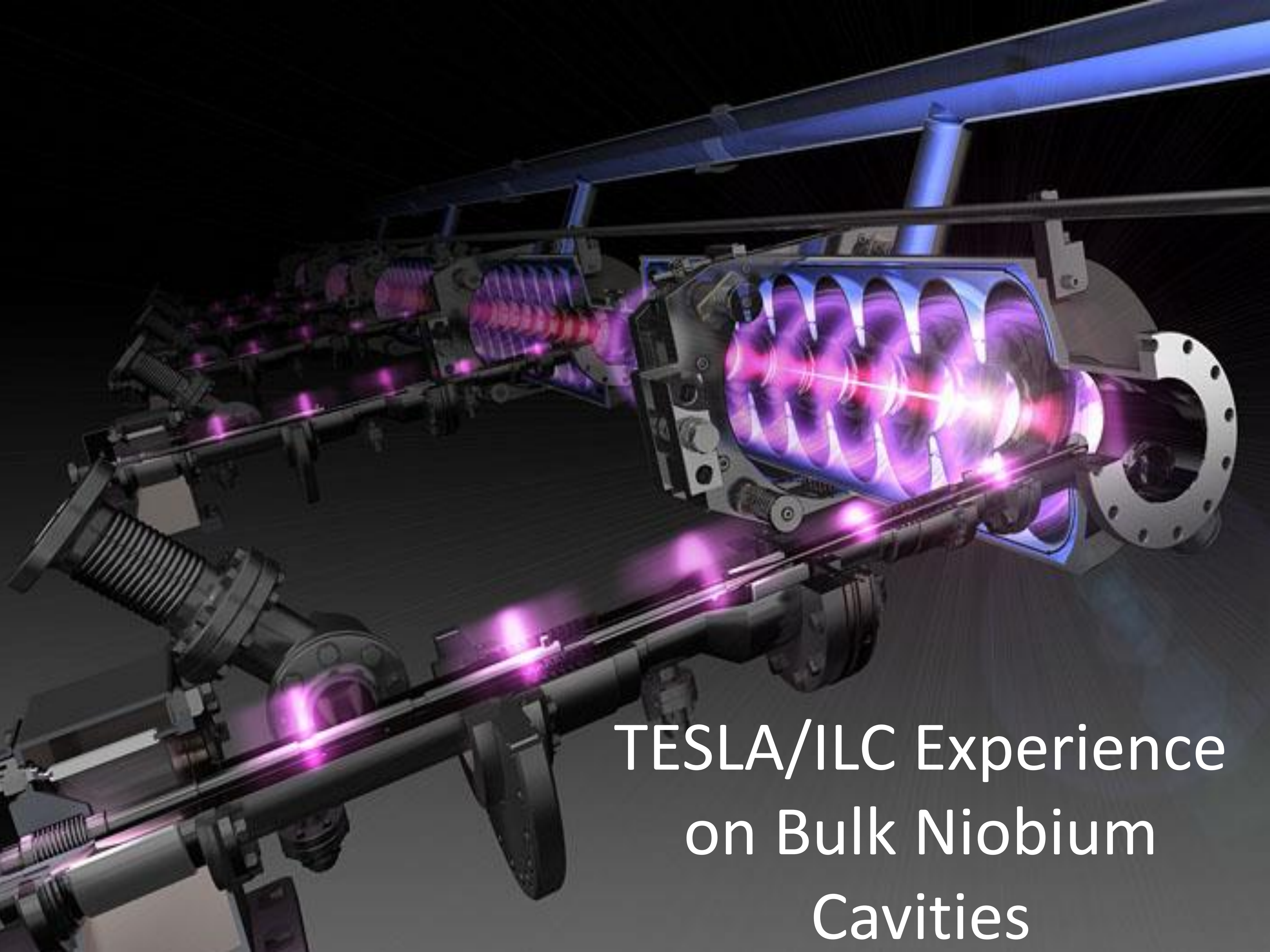
TESLA/ILC Experience on Bulk Niobium Cavities

Hasan Padamsee

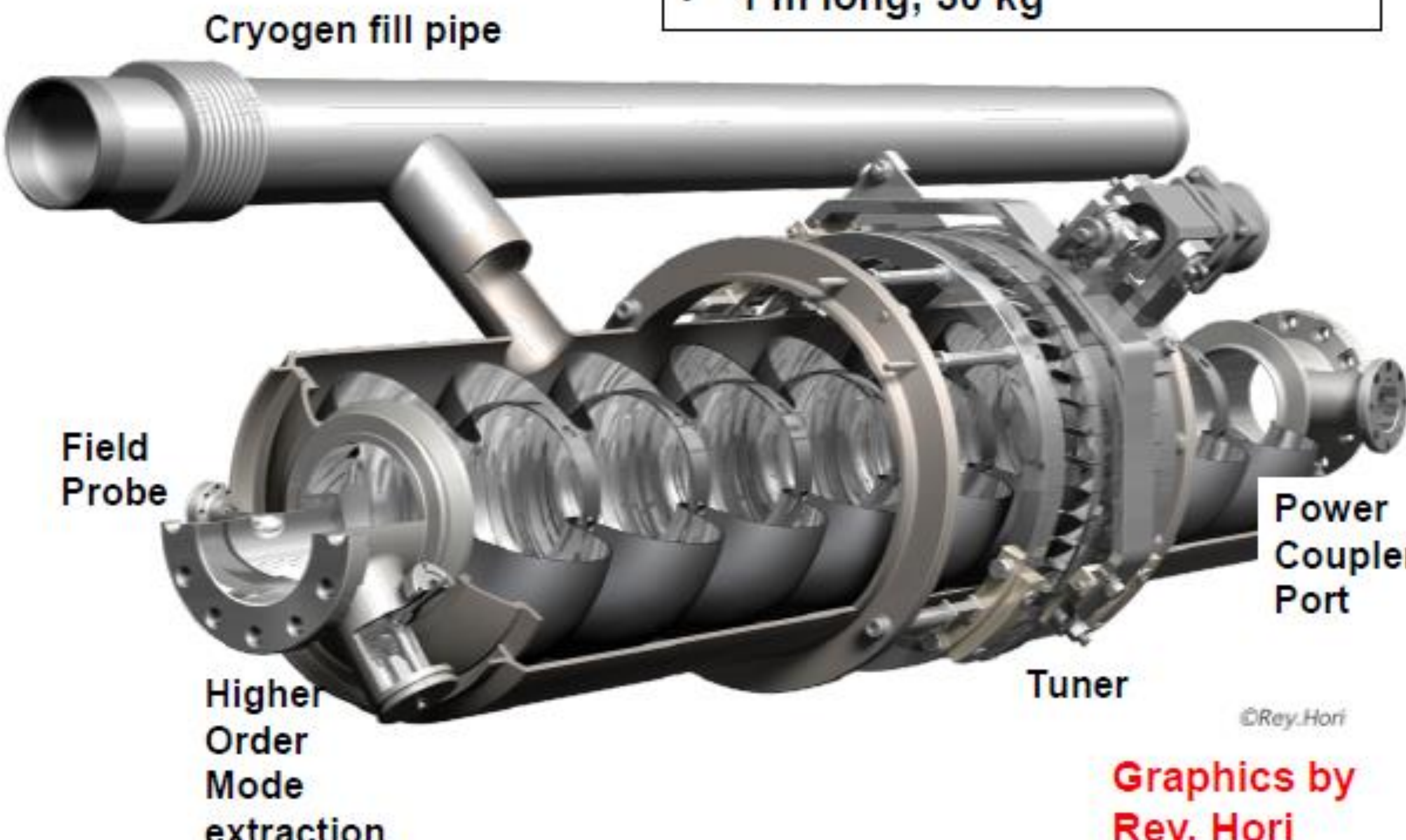
Cornell University



TESLA/ILC Experience on Bulk Niobium Cavities

The ILC SCRF Cavity:

- 9 cell 1300 MHz SW cavity
- Formed, welded niobium sheet
- 2.4 mm thick
- 1 m long; 30 kg



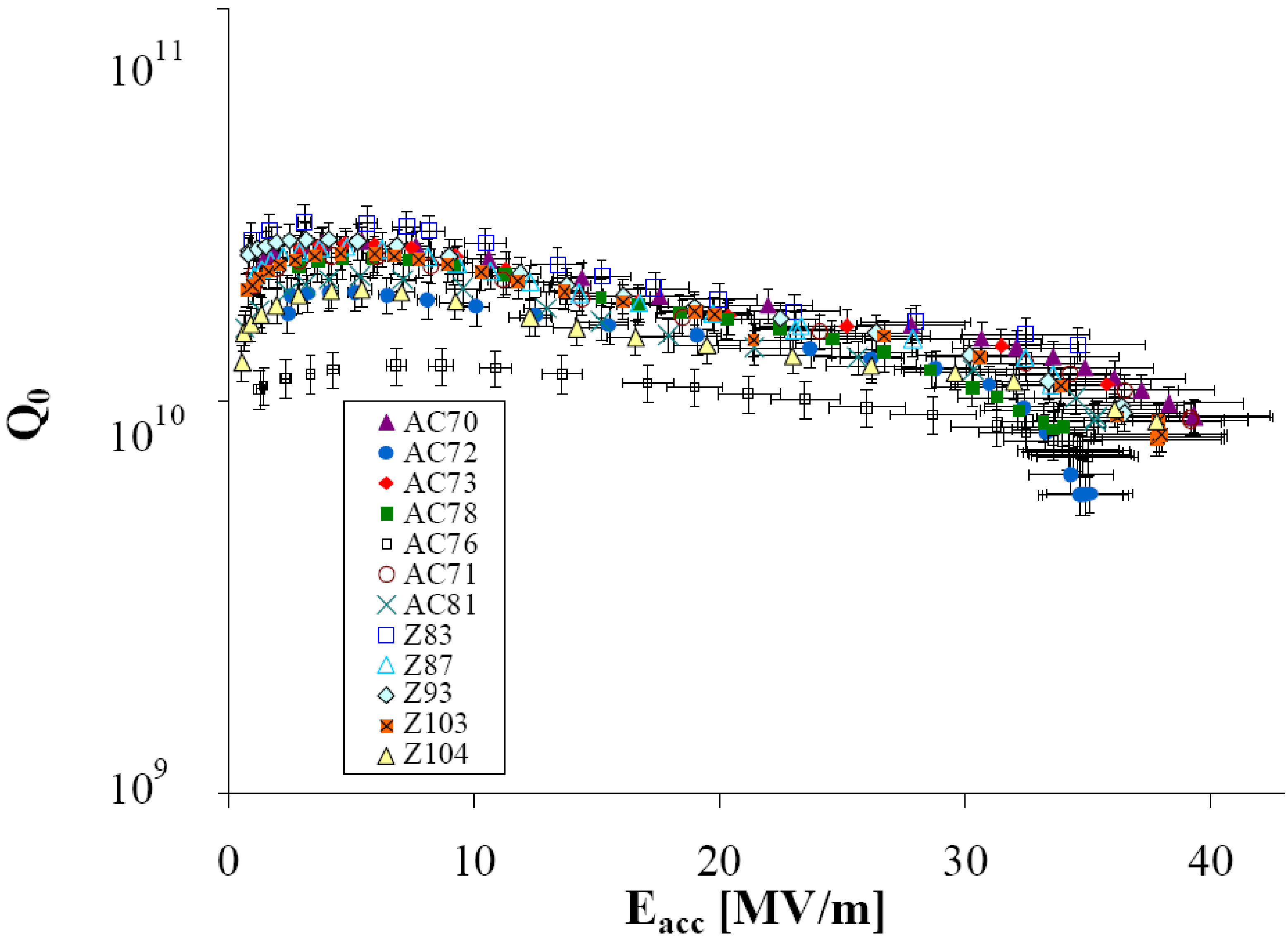
Graphics by Rey. Hori

ILC Cavity Gradient Goals

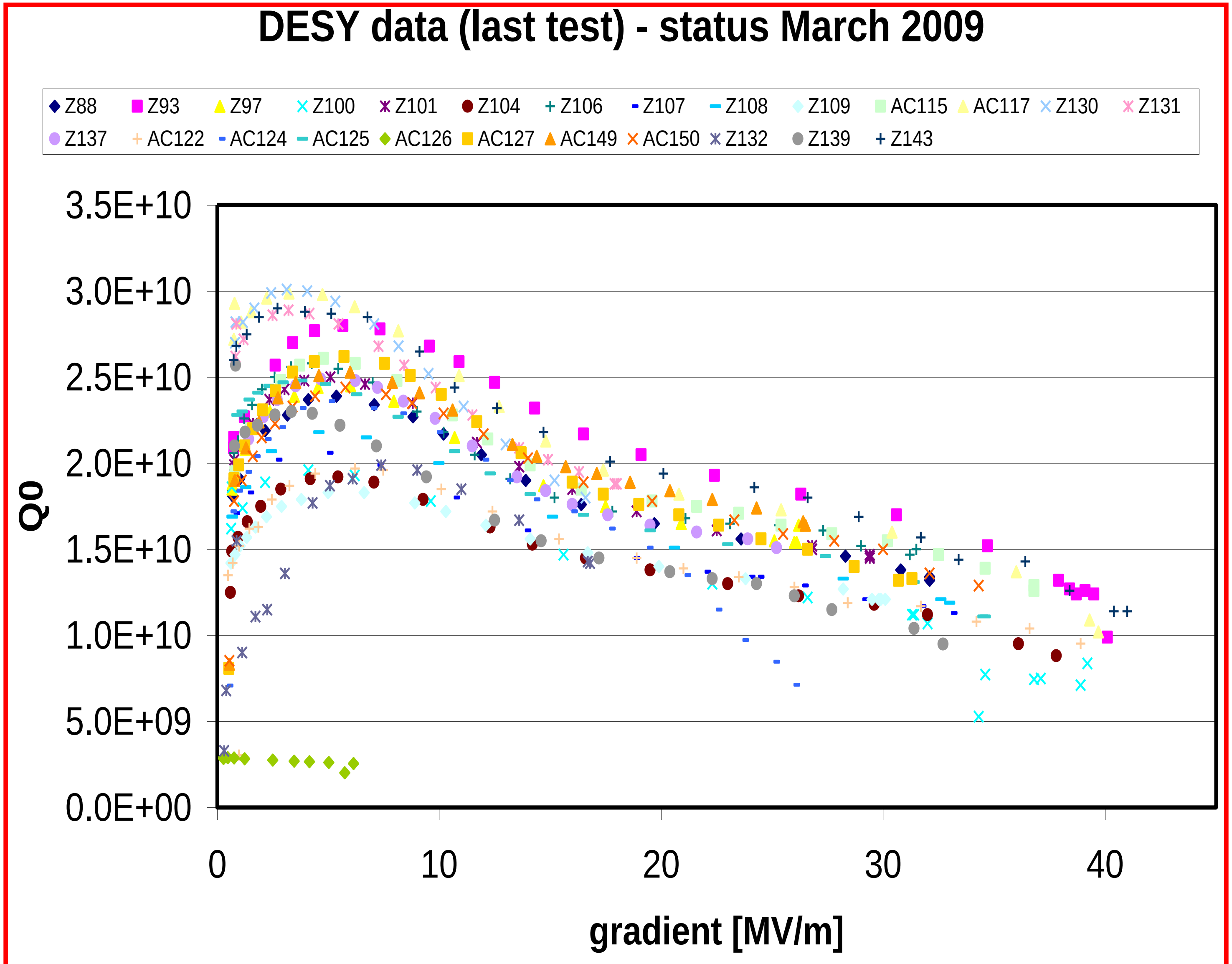
- Operating Temperature: 2K
- For Eacc = 35 $\pm$ 20% (28 – 42 MV/m)
  - Yield > 90%
- Q > 8 x10^9 at 35 MV/m
- X-rays < 10 mrem/hr
- Establish Qualified Industrial Cavity Production
- Involve expertise of many laboratories with SRF expertise
  - DESY, Jlab, Cornell, Fermilab, KEK….

Earlier High Gradient Results

Europe – DESY (12 Cavities) - 2007

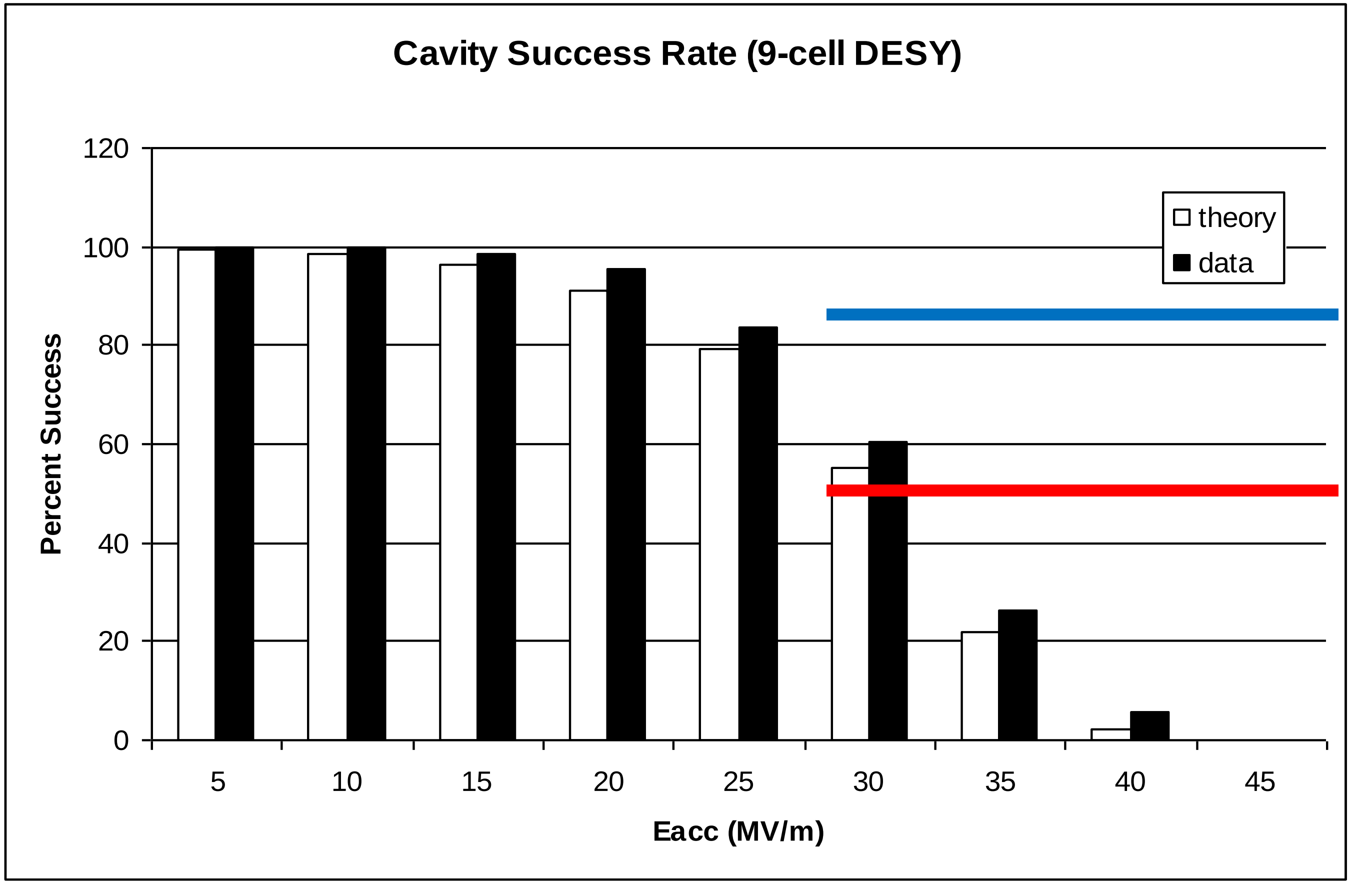


DESY 2009 (25 Cavities)



Challenge: Gradient Yield (Before 2008)

- Cavities limited by Quench



66 DESY Tests on 51

9-cell cavities, TESLA Note 2008-8

Two vendors

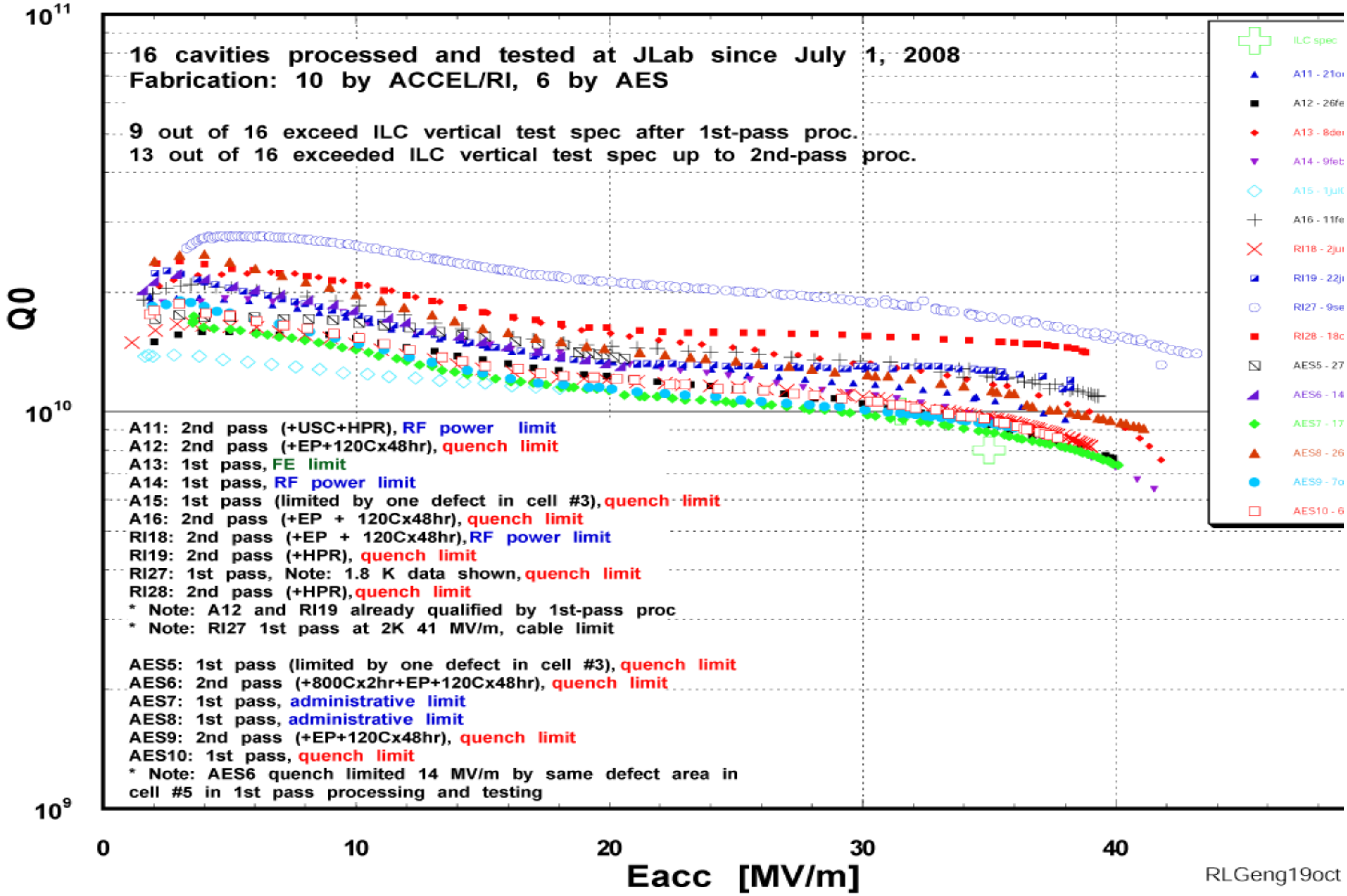
Cavities prepared by EP/HPR/800C/EP/HPR/Bake

Open bars are yields due to quench modeling

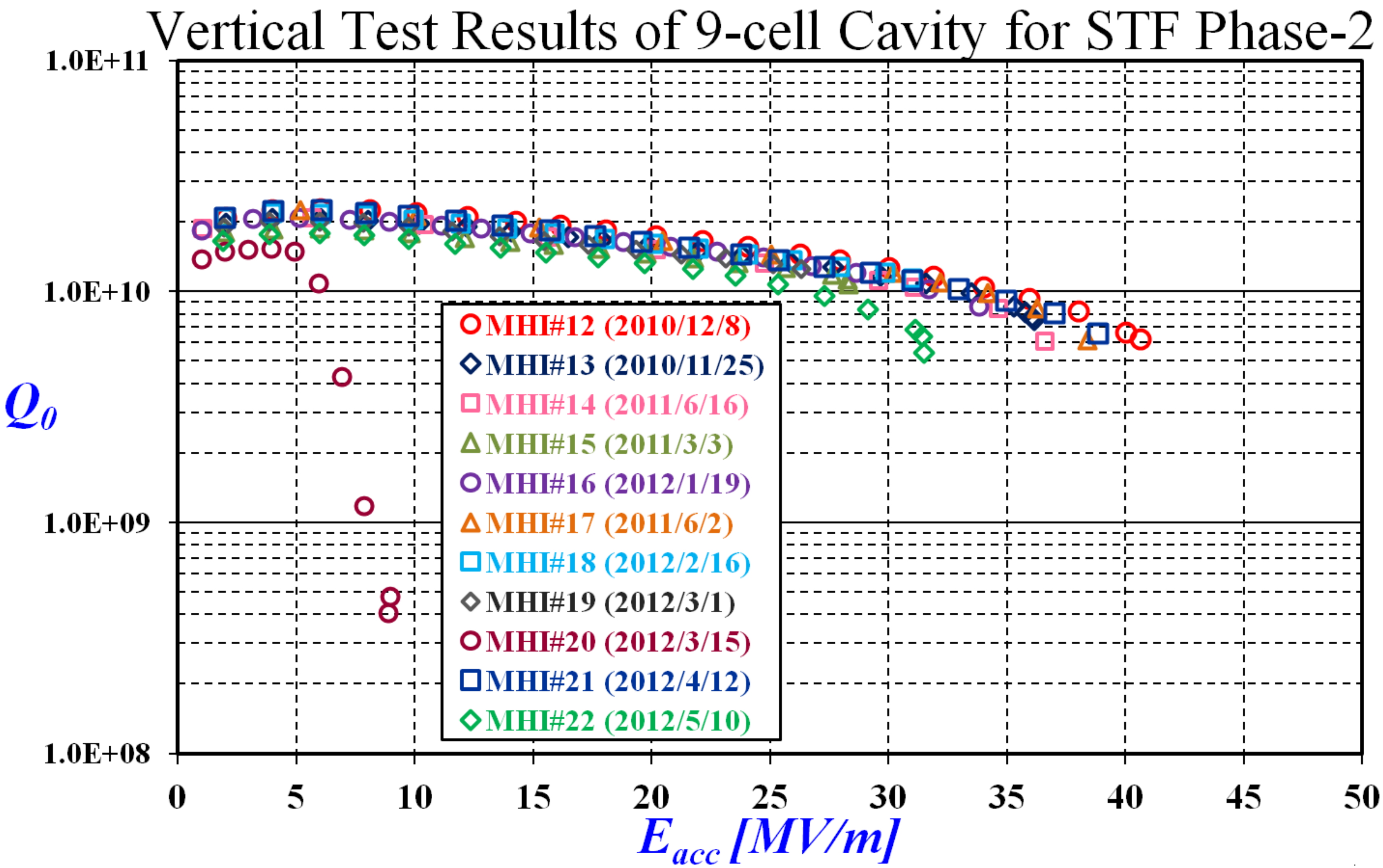
Progress in Yield Over Time

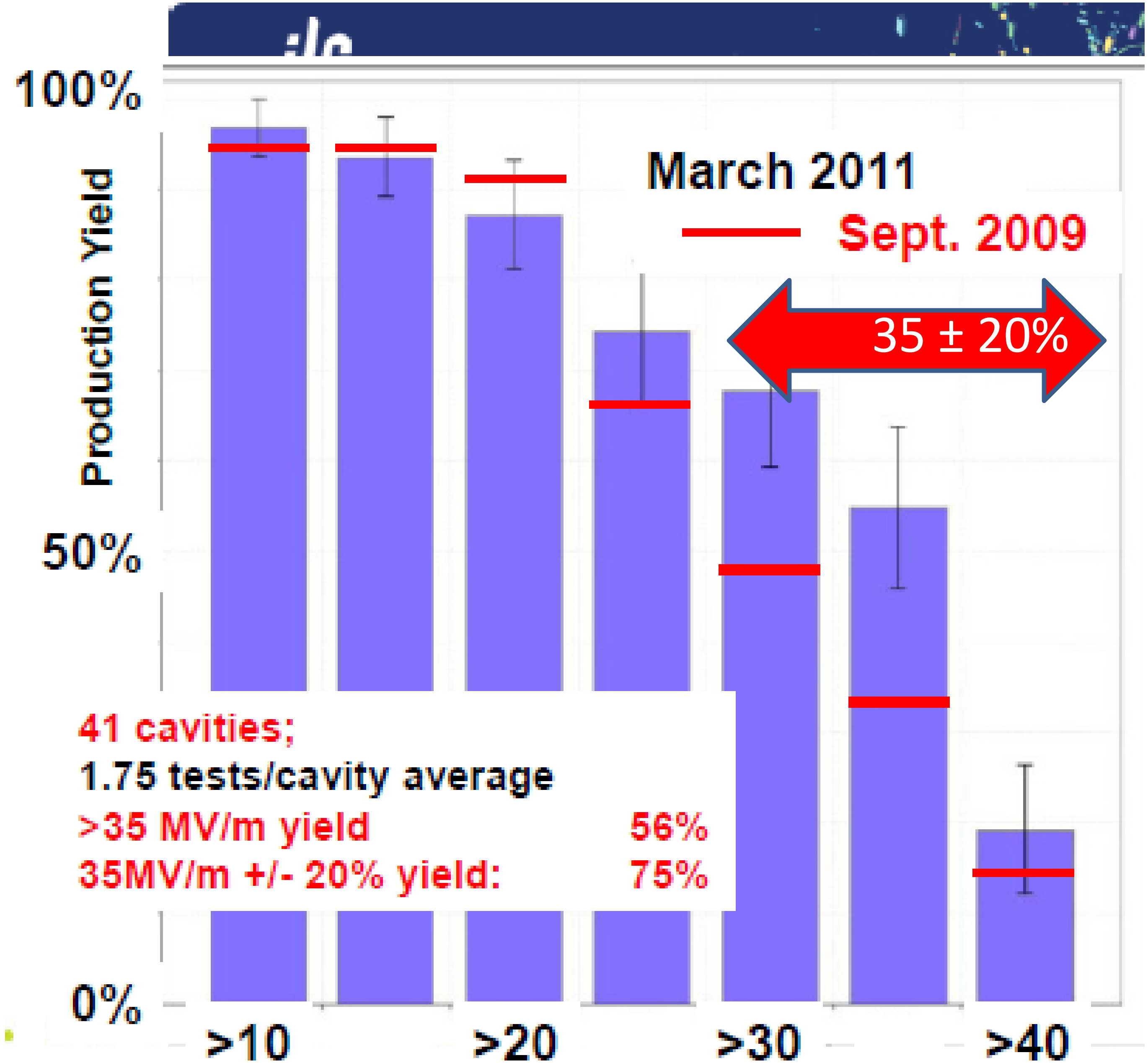
- 2009 - 2011

USA (16 Cavities) JLAB/Fermilab - 2010



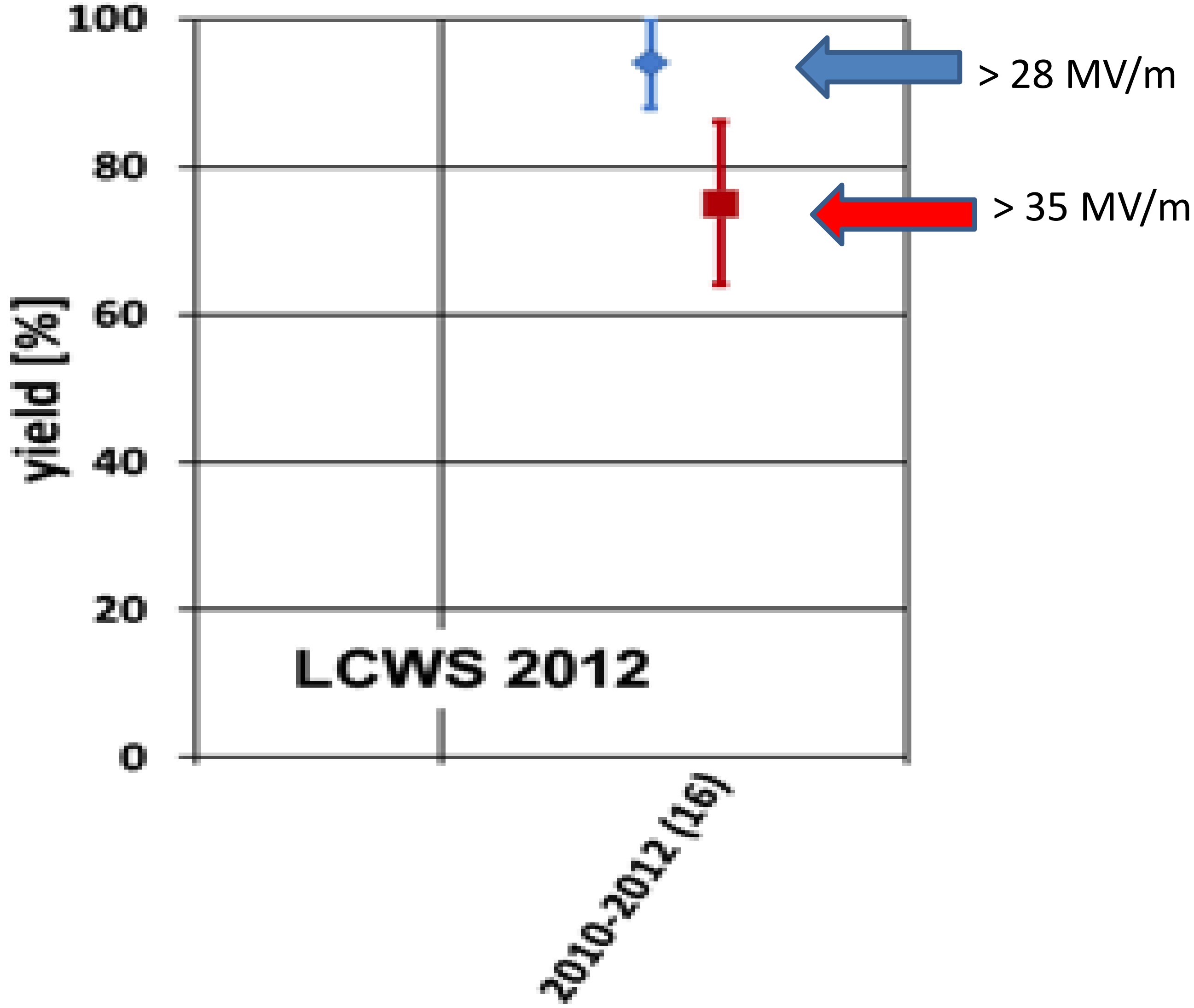
Japan (11 Cavities) - 2012




100%
50%
0%
Production Yield
March 2011
Sept. 2009
35 ± 20%
41 cavities;
1.75 tests/cavity average
>35 MV/m yield 56%
35MV/m +/- 20% yield: 75%
>10
>20
>30
>40

75%

And Now !! 2012 (2nd Pass Yield)



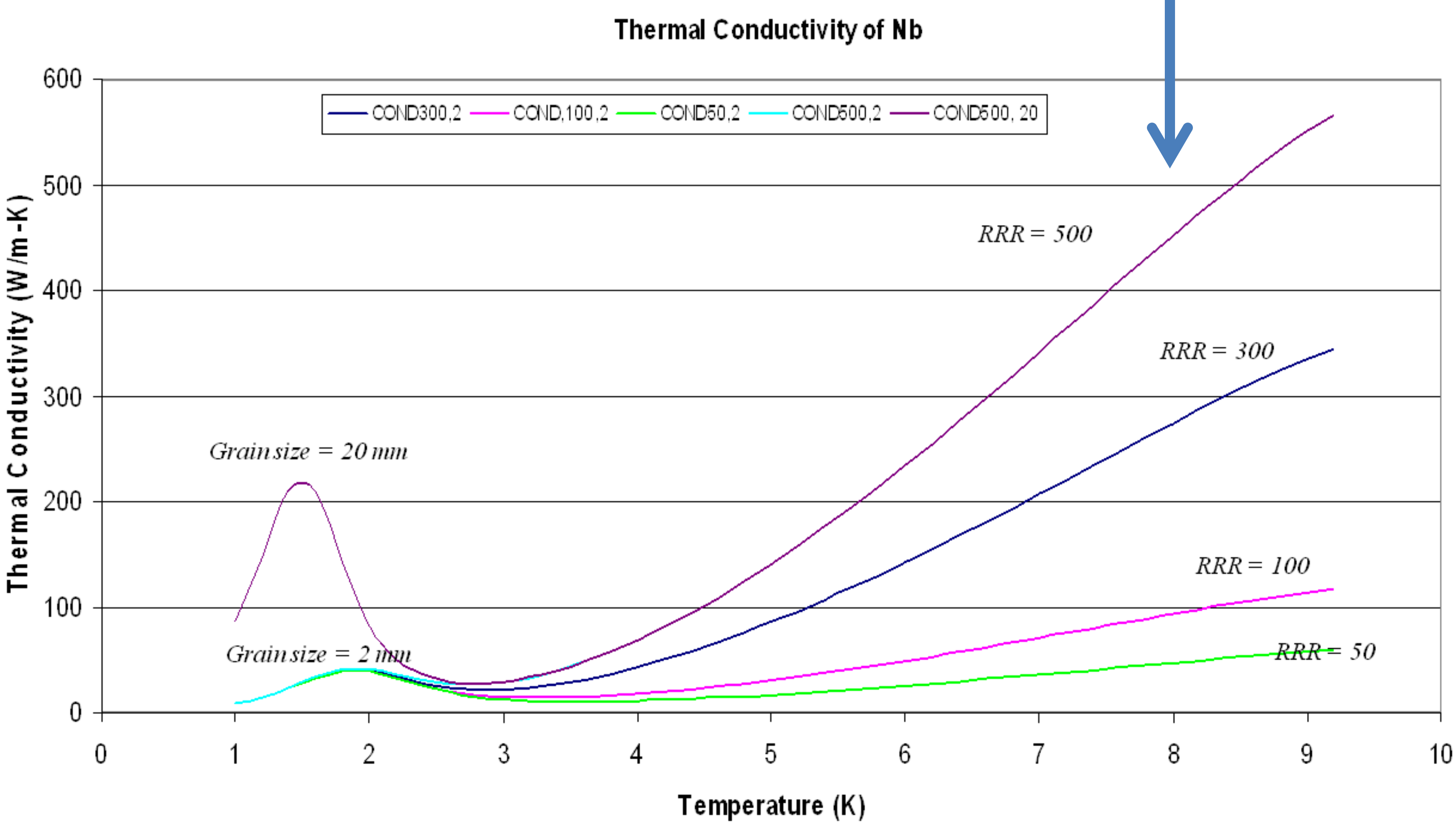
Which Steps Improved Performance for Higher Yield?

- Steps Marked by **
- Reduce field emission
- Further treatment for non-performing cavities

1st Treatment – The Full ILC Procedure Blood, Guts and… Glory

- Start with high RRR (>300) Nb
  - For high thermal conductivity to remove heating from imperfections
- Exercise great care in fabrication of parts, cleaning and electron beam welding
- Electropolish 100 mm (bulk EP)
  - To remove surface damage layer
- Rinse with ethanol (or soapy water) and ultrasound for few hours
  - To dissolve S particles (avoid field emission)
- High Pressure water rinse (> 100 bar) - HPR
- Furnace treatment 800 C for 2 hours
- Remove H dissolved in bulk during EP
- Light EP (20mm)
  - to remove surface contaminants from furnace
- HPR many hours
  - To remove field emitters
- Evacuate
- Bake at 120 for 48 hours
- To cure the high field Q-slope (cause still a mystery)
- RF test at 2 K

Thermal Conductivity 4 – 10 K is proportional to Nb purity (RRR)



1^{st} Treatment
The ILC Preparation Procedure

- Start with high RRR (>300) Nb
  - For high thermal conductivity to stabilize heating at imperfections
- **Exercise great care and cleanliness in fabrication of parts, cleaning and electron beam welding**
- Electropolish 100 mm (bulk EP)
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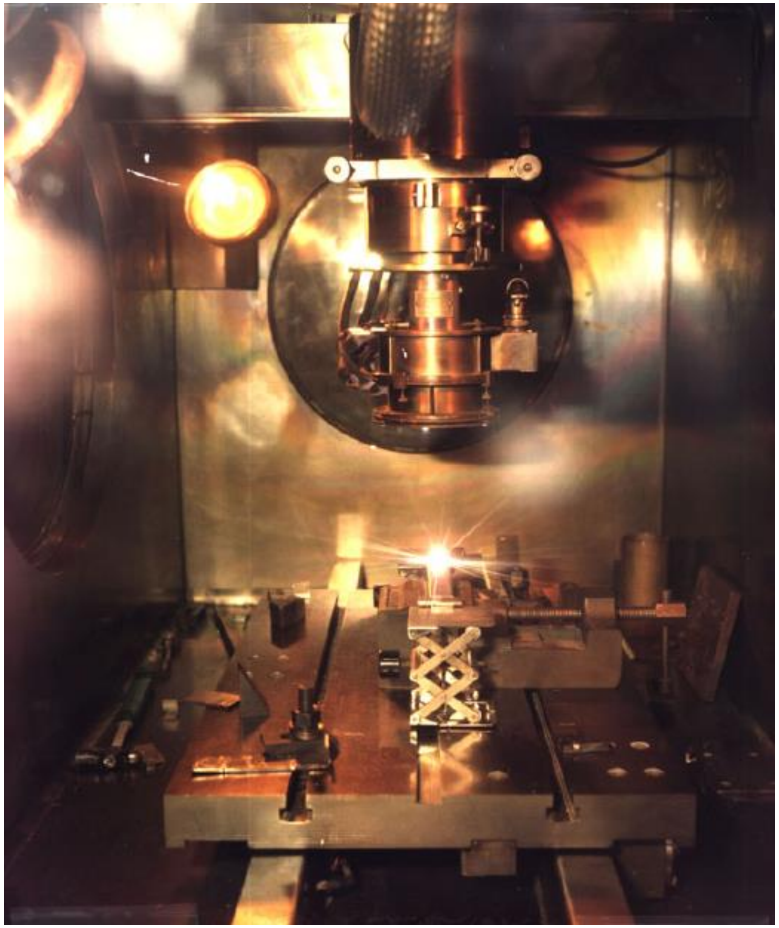
Electron Beam Welding



1st Treatment
The ILC Procedure

- Start with high RRR (>300) Nb
  - For high thermal conductivity to stabilize heating at imperfections
- Exercise great care and cleanliness in fabrication of parts, cleaning and electron beam welding
- Electropolish 100 μm (bulk EP)
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- High Pressure water rinse (> 100 bar) - HPR
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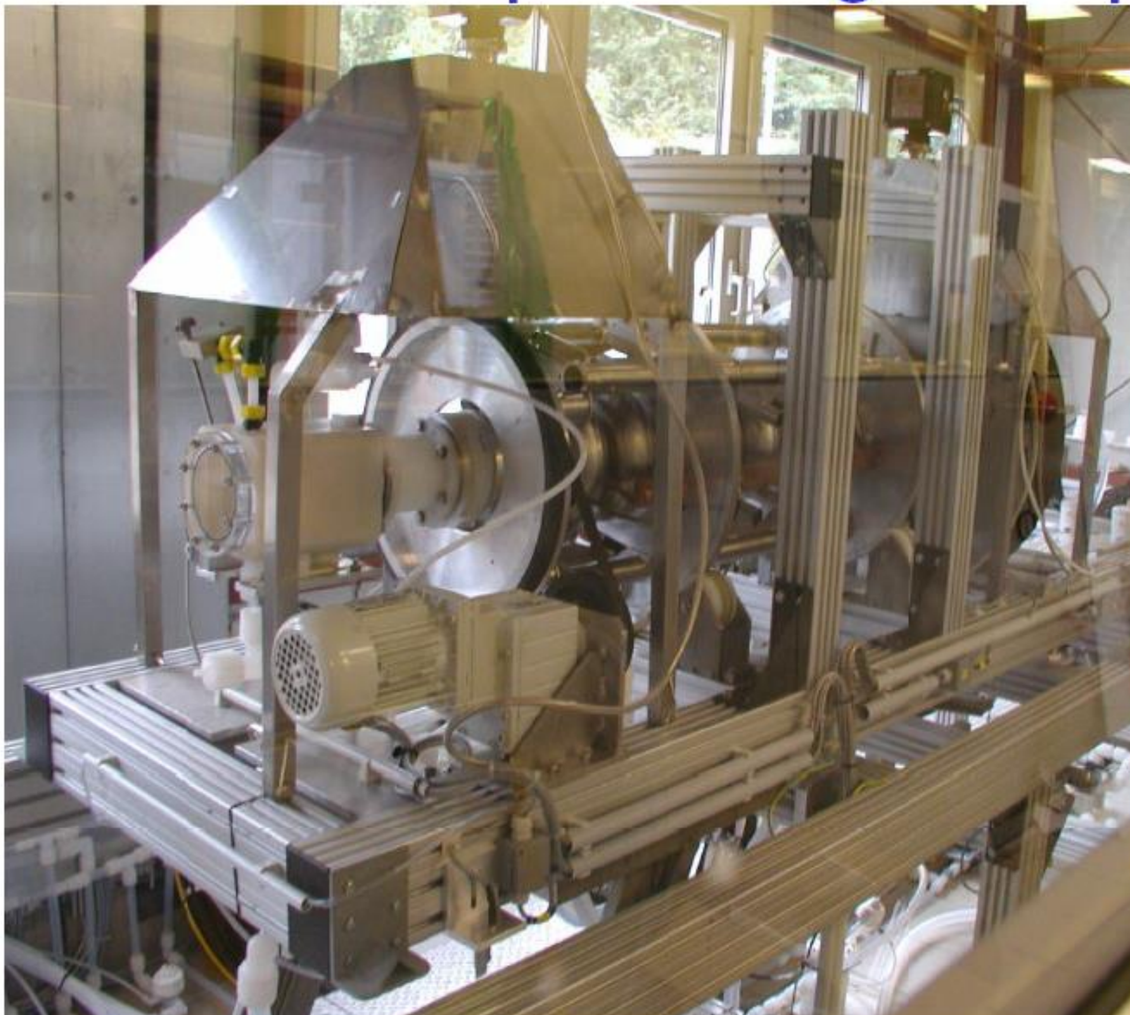
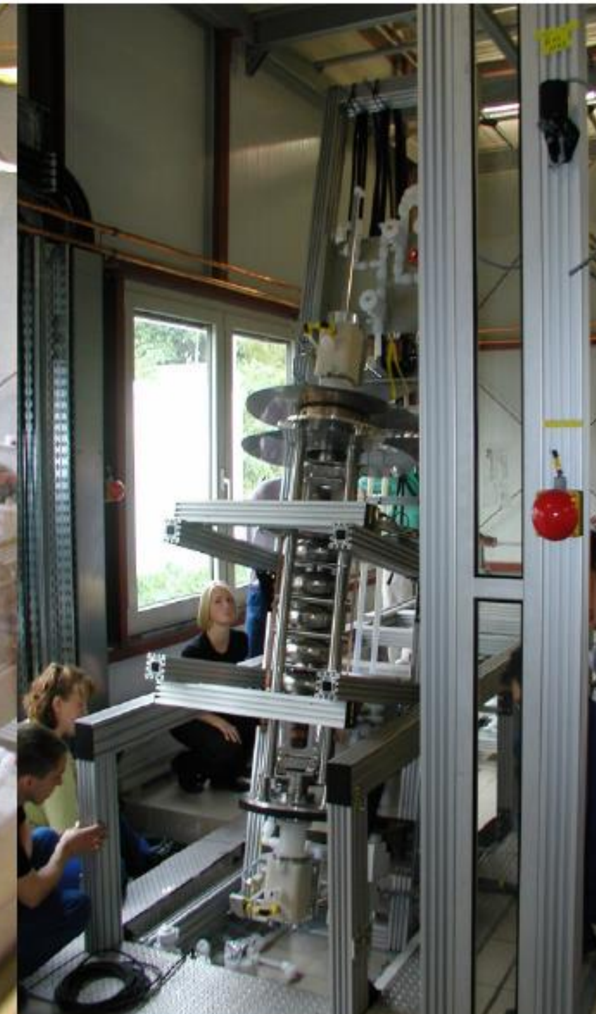
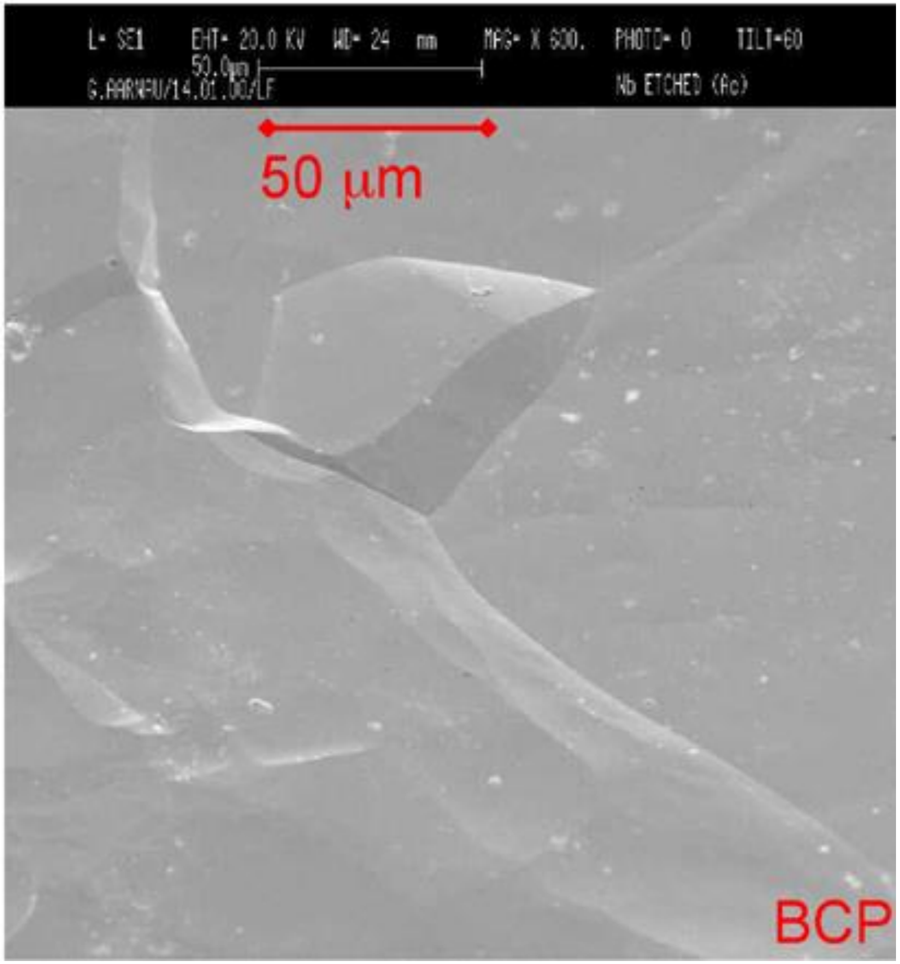
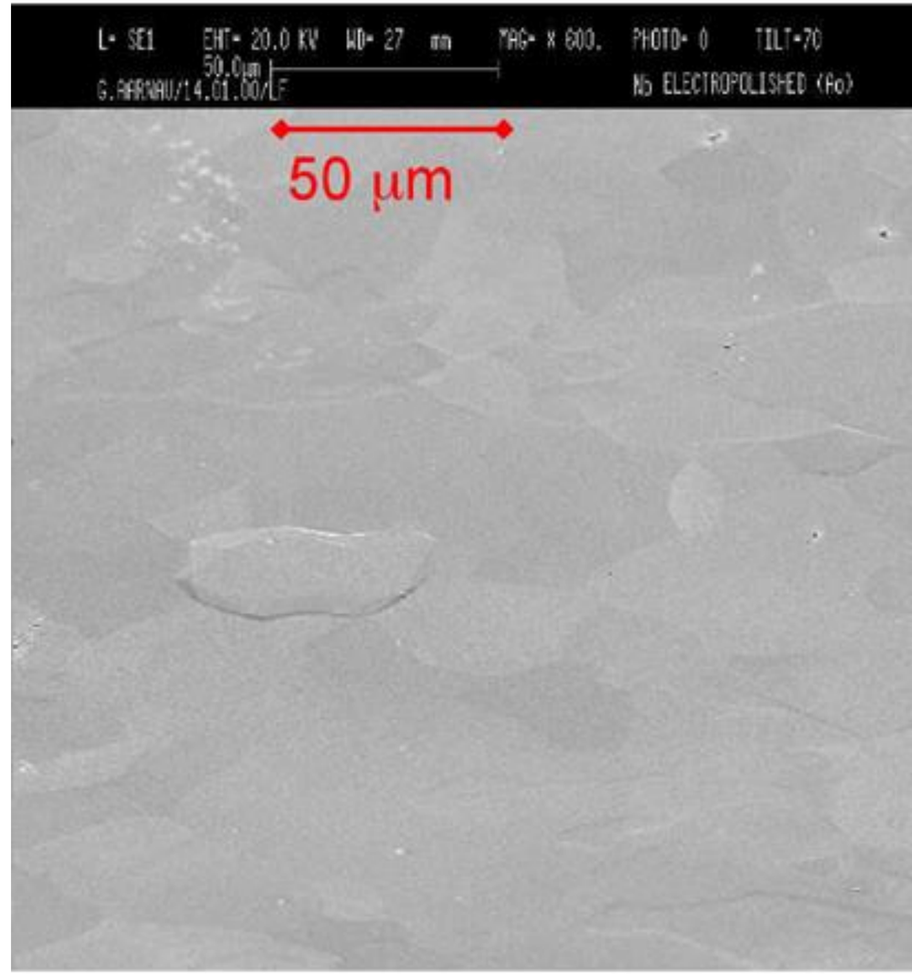
Electropolishing Setup at DESY







BCP gives steps at grain boundaries (many microns)



EP gives smooth surface

1st Treatment
The ILC Procedure

- Start with high RRR (>300) Nb
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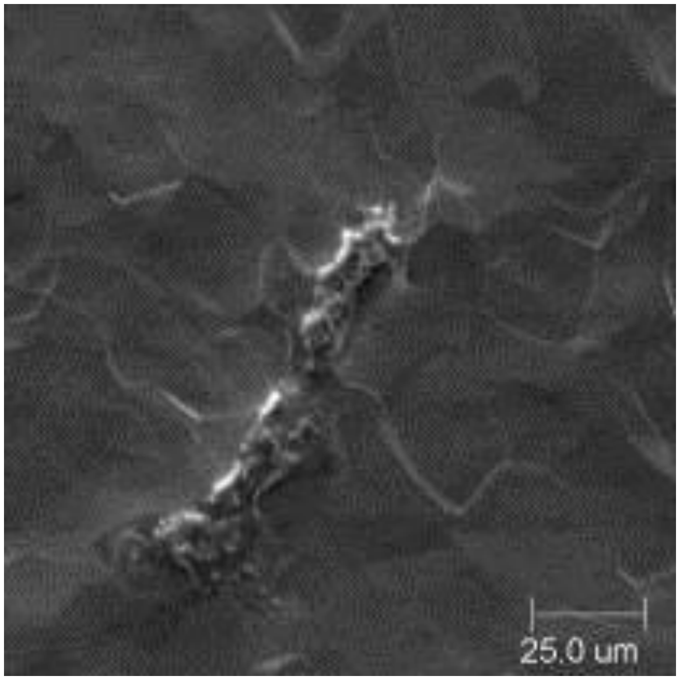
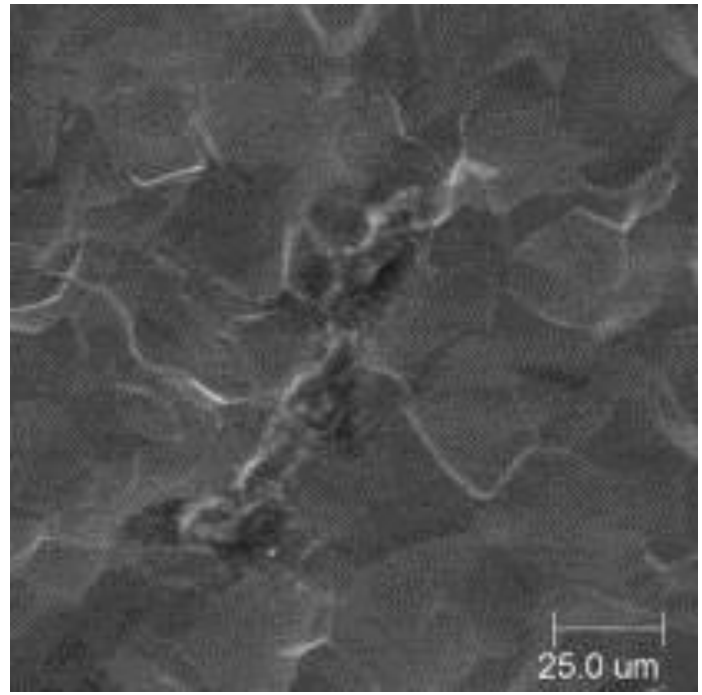
Field Emission Reduction



S particle deposited on sample during EP

(Cornell Basic R&D)



Dissolved S particle,

but leaves an slight imprint,

Impact unknown

Field Emission Reduction By Removing S

- Post-Chemistry Cleaning
  - Ethanol rinsing
  - Ultrasonic cleaning (De-ionized water + detergent)

B. van der Horst, SRF2007

1st Treatment
The ILC Procedure

- Start with high RRR (>300) Nb
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- Exercise great care and cleanliness in fabrication of parts, cleaning and electron beam welding
- Electropolish 100 mm (bulk EP)
  - To remove surface damage layer
- Rinse with ethanol (or soapy water) and ultrasound for few hours
  - To dissolve S particles (avoid field emission)
- **High Pressure water rinse (> 100 bar) - HPR**
- Furnace treatment 800 C for 2 hours
- Remove H dissolved in bulk during EP
- Light EP (20mm)
  - to remove surface contaminants from furnace
- HPR many hours
  - To remove field emitters
- Evacuate
- Bake at 120 for 48 hours
- To cure the high field Q-slope (cause still a mystery)
- RF test at 2 K

HPR and Assembly at Cornell in Class 100 Clean Room

< 100 particles/cu.ft > 1 μm

1^{st} Treatment- The ILC Procedure

- Start with high RRR (>300) Nb
  - For high thermal conductivity to stabilize heating at imperfections
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  - Remove H dissolved in bulk during EP
- Light EP (20mm)
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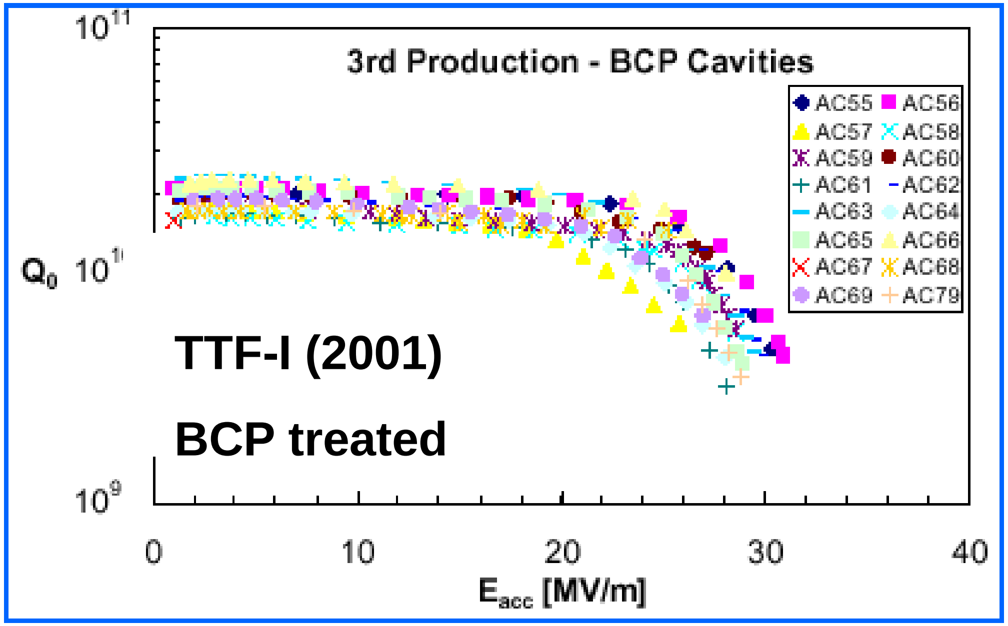
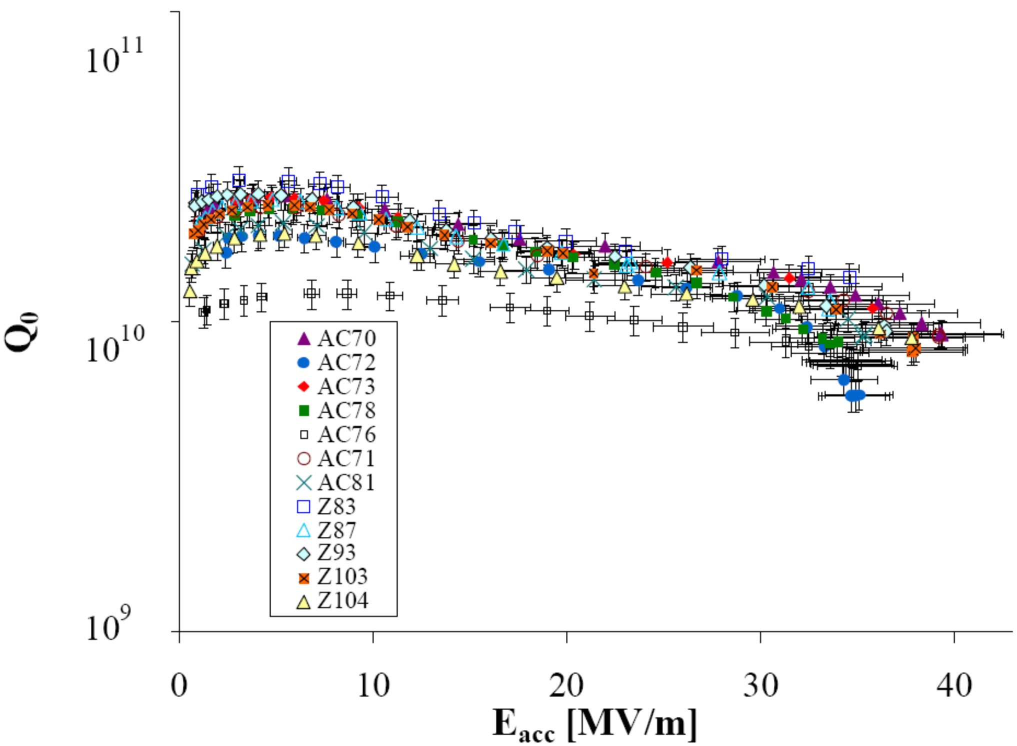
- HPR many hours
  - To remove field emitters
- Evacuate
- Bake at 120 for 48 hours
  - To cure the high field Q-slope (cause still a mystery)
- RF test at 2 K

Furnaces Used at Different Labs for Removing H



High Field Q-slope limits BCP prepared cavities



Baking at 120 C for 48 hours reduces high field Q-slope

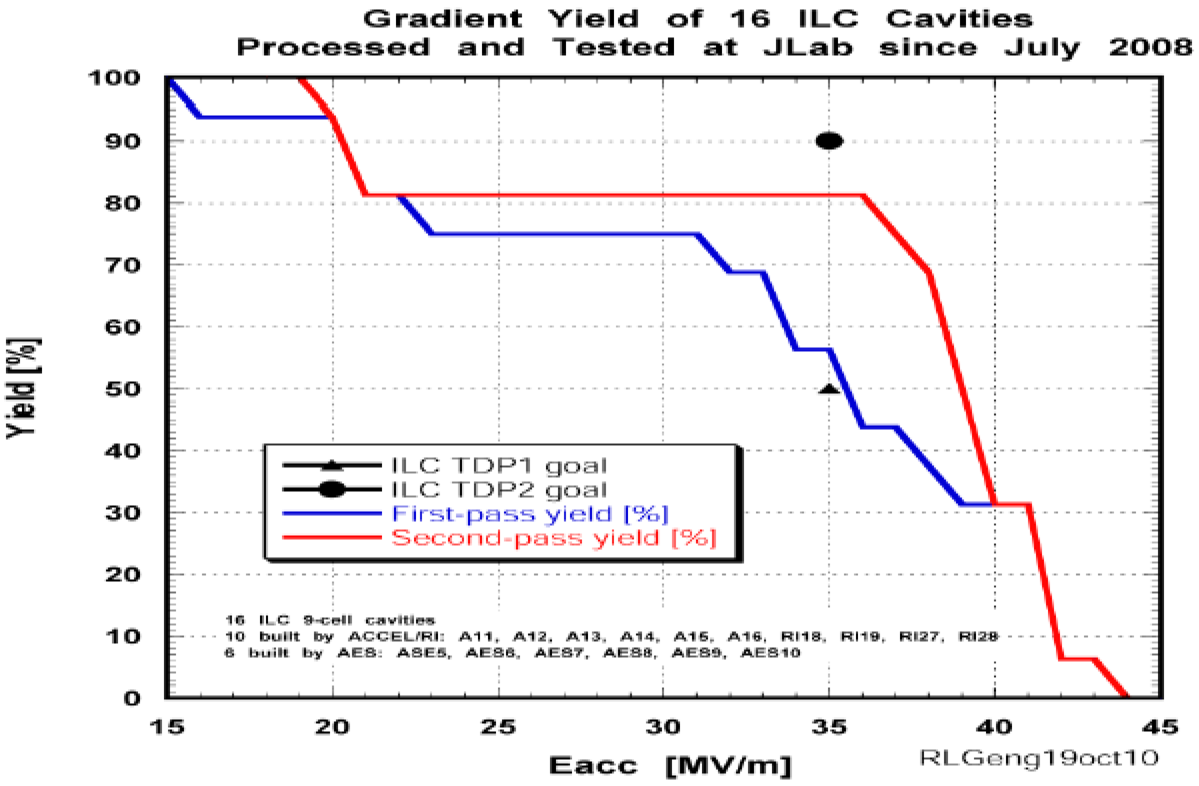
H. Padamsee

1^{st} Treatment
The ILC Procedure

- Start with high RRR (>300) Nb
  - For high thermal conductivity to stabilize heating at imperfections
- Exercise great care and cleanliness in fabrication of parts, cleaning and electron beam welding
- Electropolish 100 mm (bulk EP)
  - To remove surface damage layer
- Rinse with ethanol (or soapy water) and ultrasound for few hours
  - To dissolve S particles (avoid field emission)
- High Pressure water rinse (> 100 bar) - HPR
- Furnace treatment 800 C for 2 hours
- Remove H dissolved in bulk during EP
- Final Treatment
- Light EP (20μm)
  - to remove surface contaminants from furnace
- HPR many hours
  - To remove field emitters
- Evacuate
- Bake at 120 for 48 hours
  - To cure the high field Q-slope (cause still a mystery)
- RF test at 2 K

Early 2011
2nd Pass Yield Improvement

Gradient yield curve
ACCEL/RI and AES cavities without bias



For Cavities Limited by Excess Field Emission

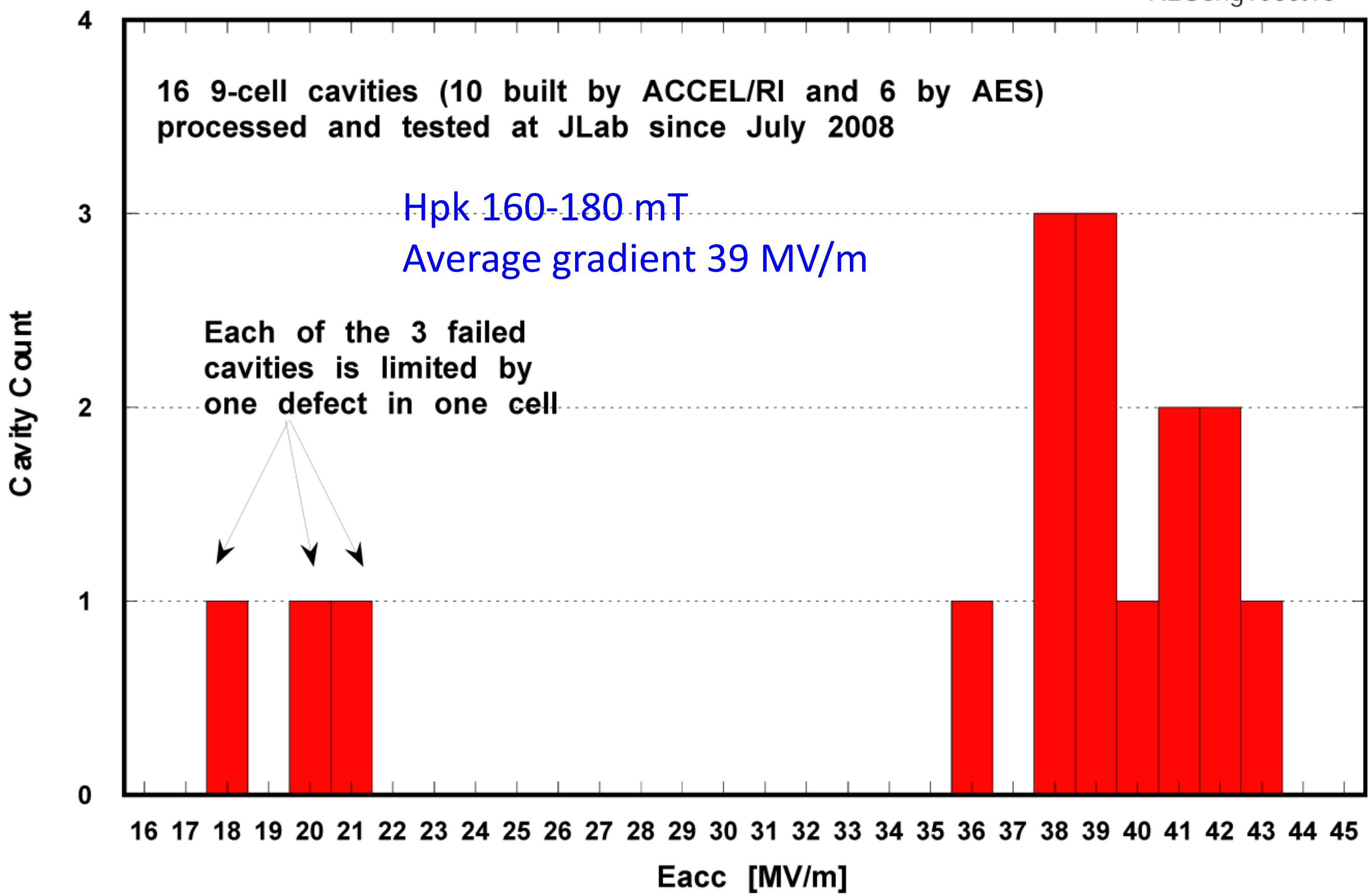
- High Pressure Rinse Again
  - Frequent recovery
- OR
- Repeat final EP processing
- 2^{nd} Test Qualifies high gradient

Small Fraction of Cavities Limited by Quench < 25 MV/m

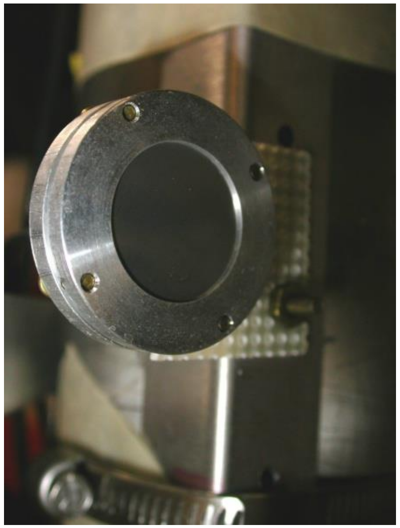
- Identify Quench Location by
  - Thermometry
  - 2^{nd} Sound

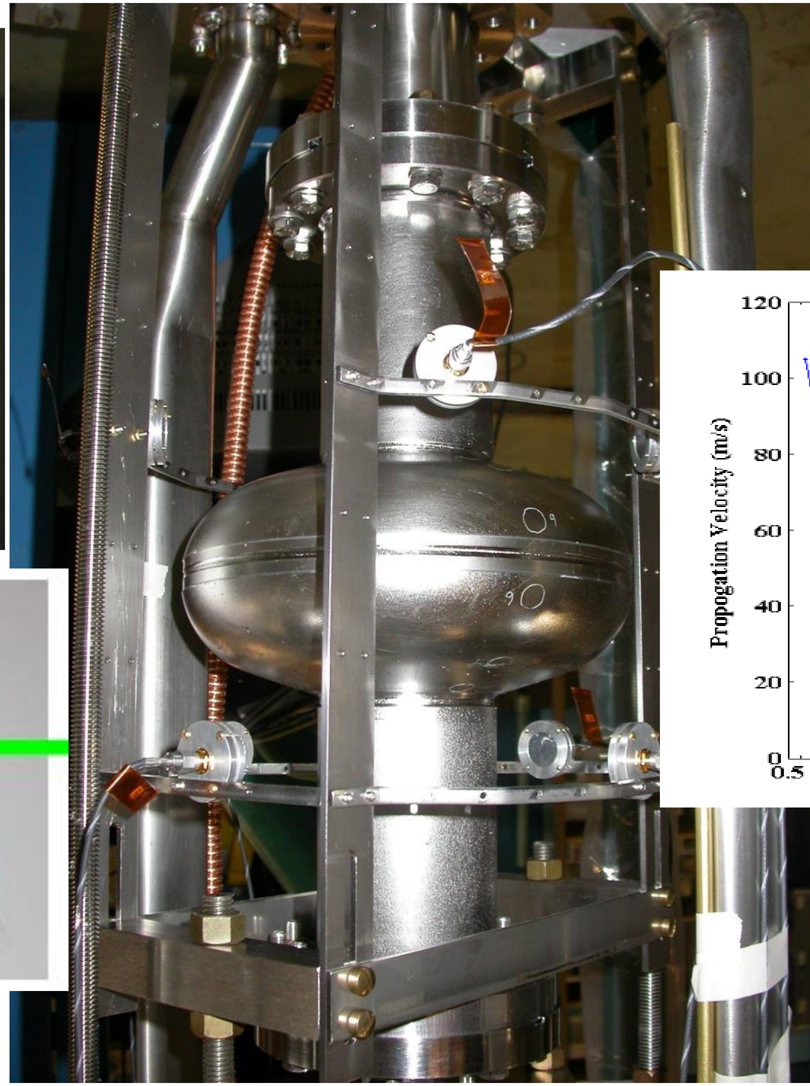
Options for Few Cavities Which Fail to Meet High Gradient on First Test

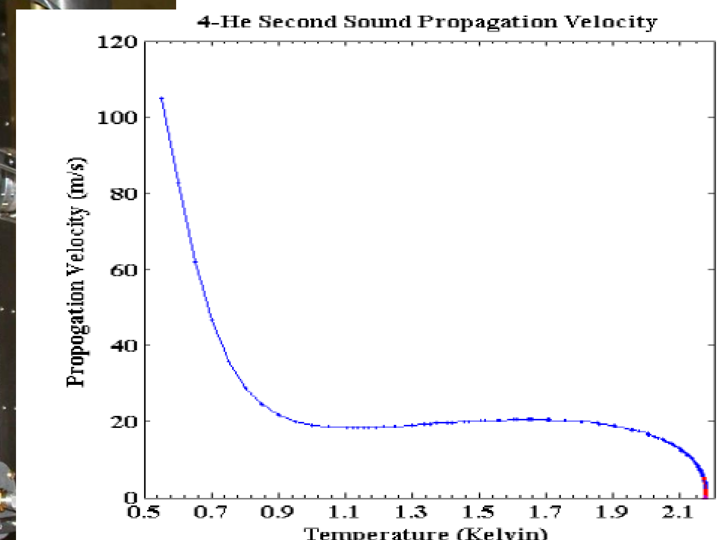
RLGeng19oct10



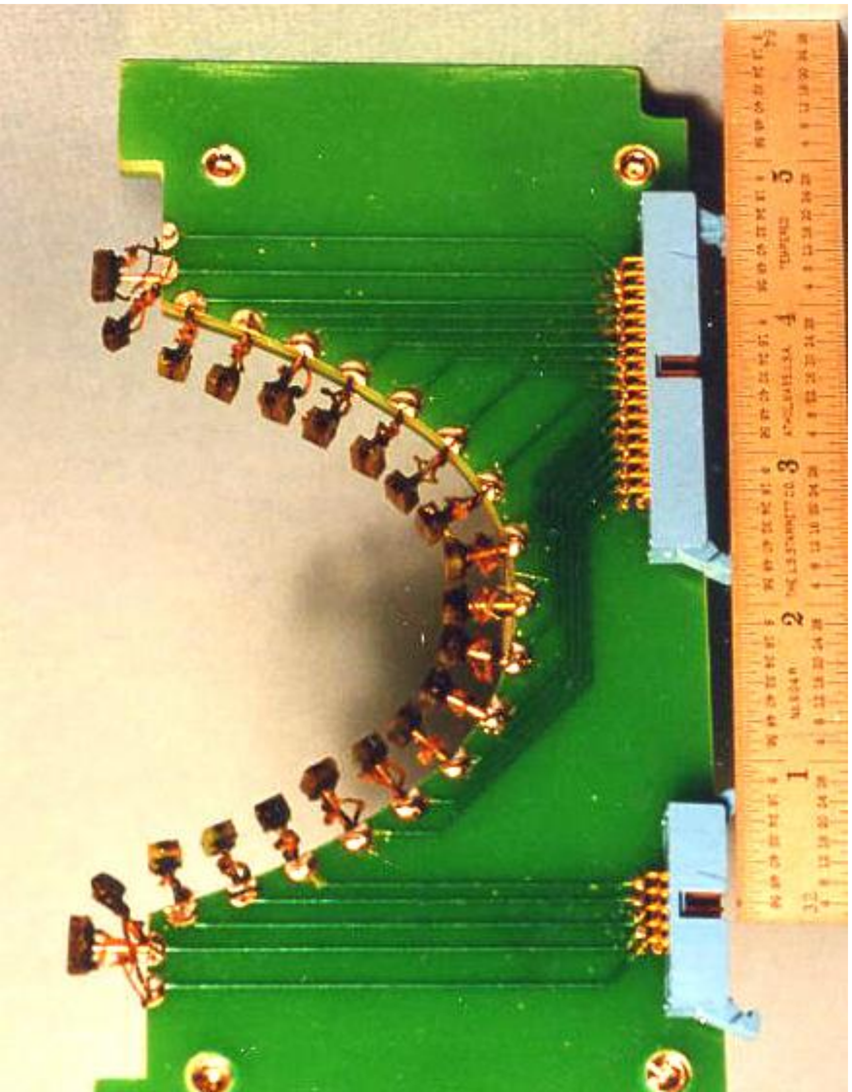
Quench Location Using Second Sound in Superfluid He



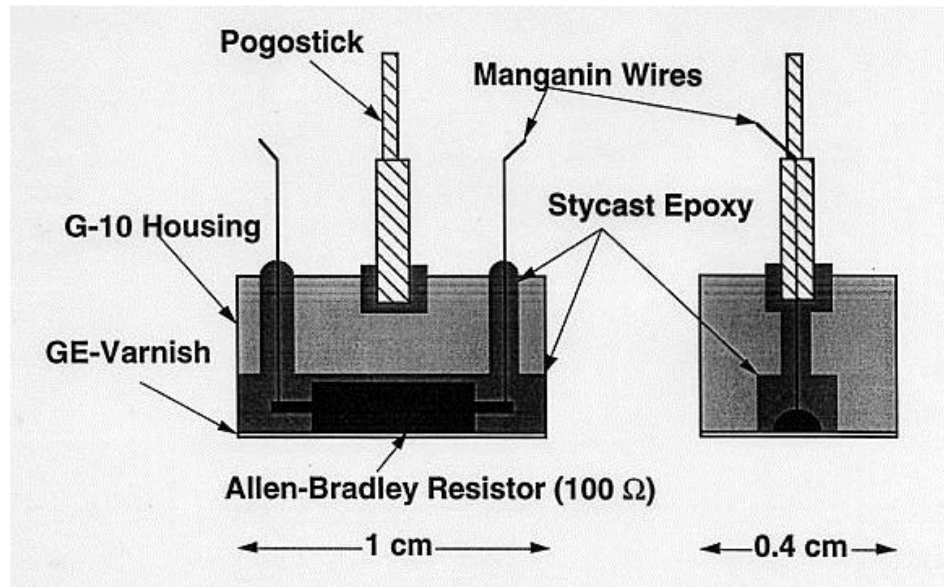




Cornell Thermometry System

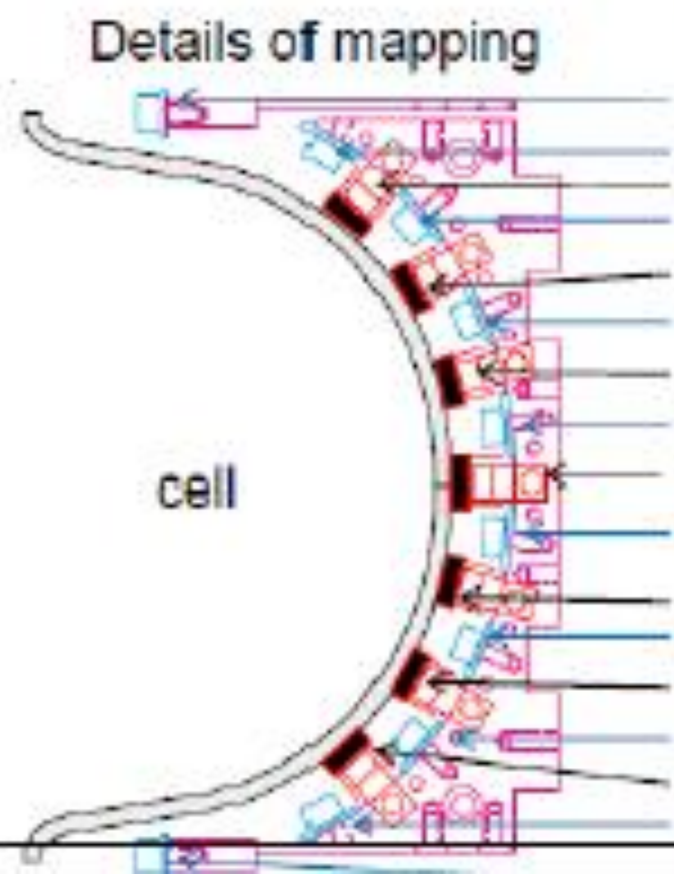


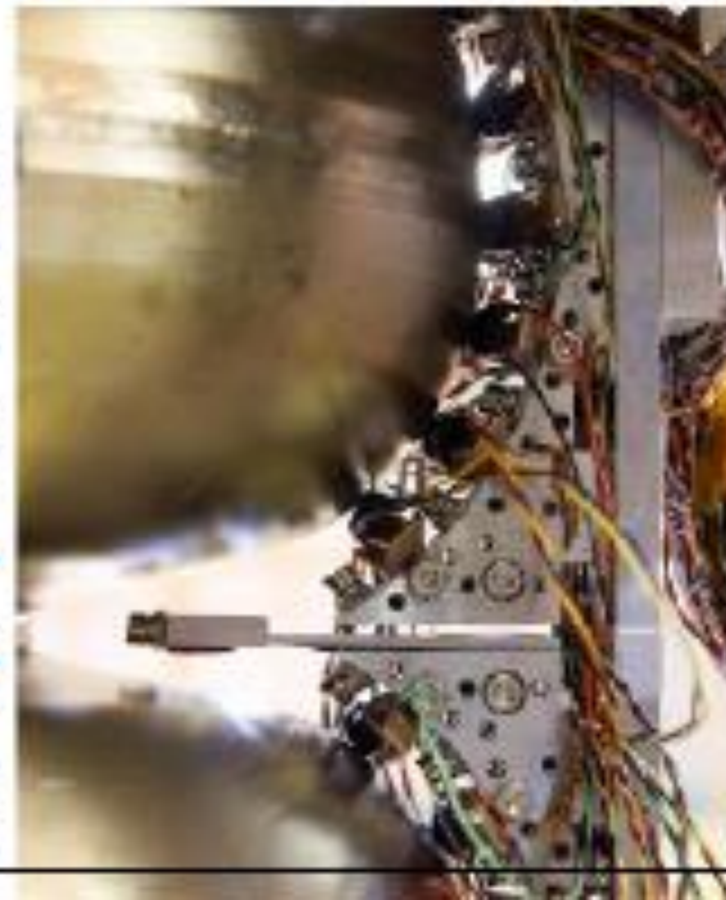
Individual Thermometers



KEK

- **Thermal/radiation mapping**
  - Carbon resistors and PIN diodes





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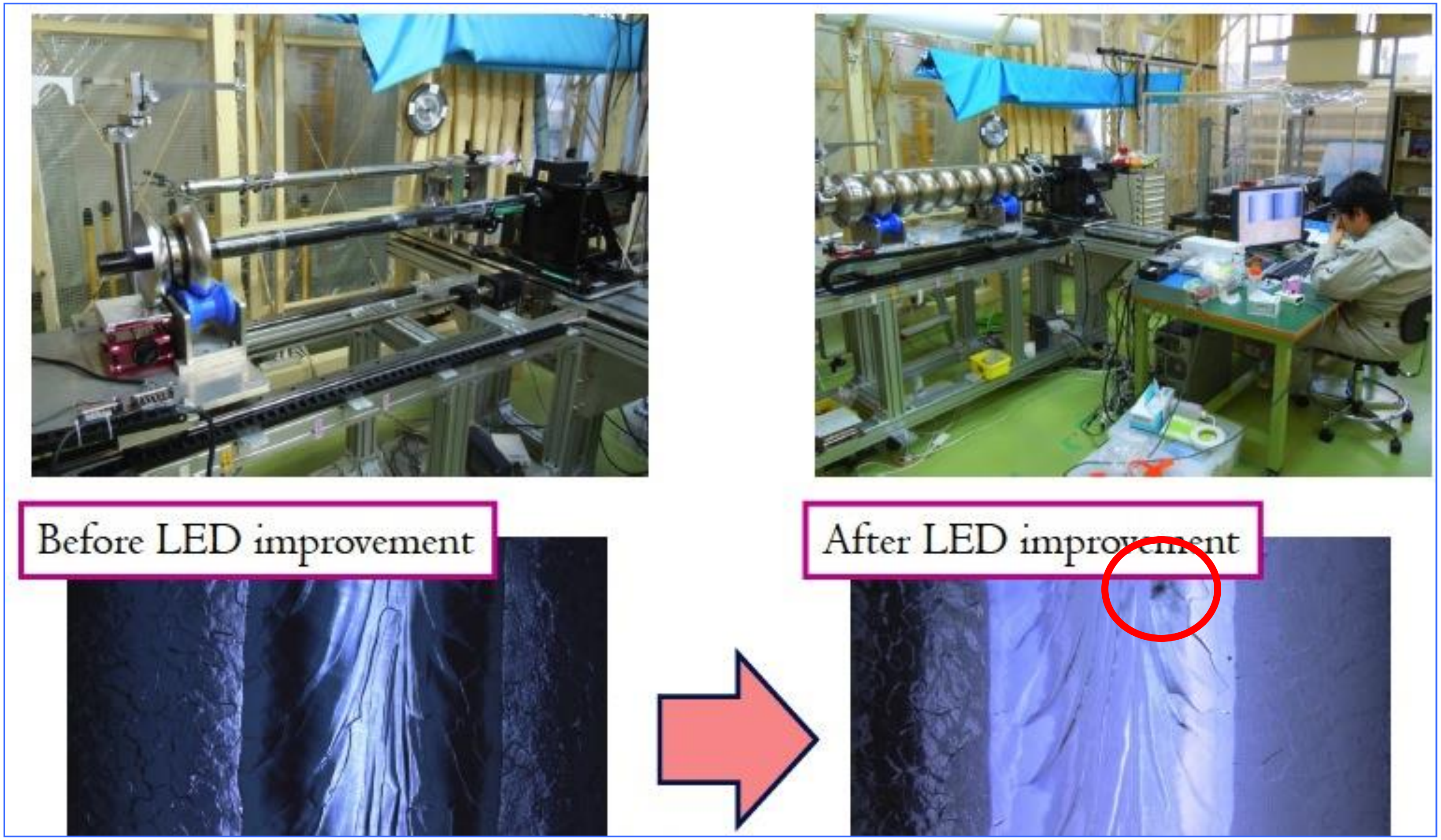
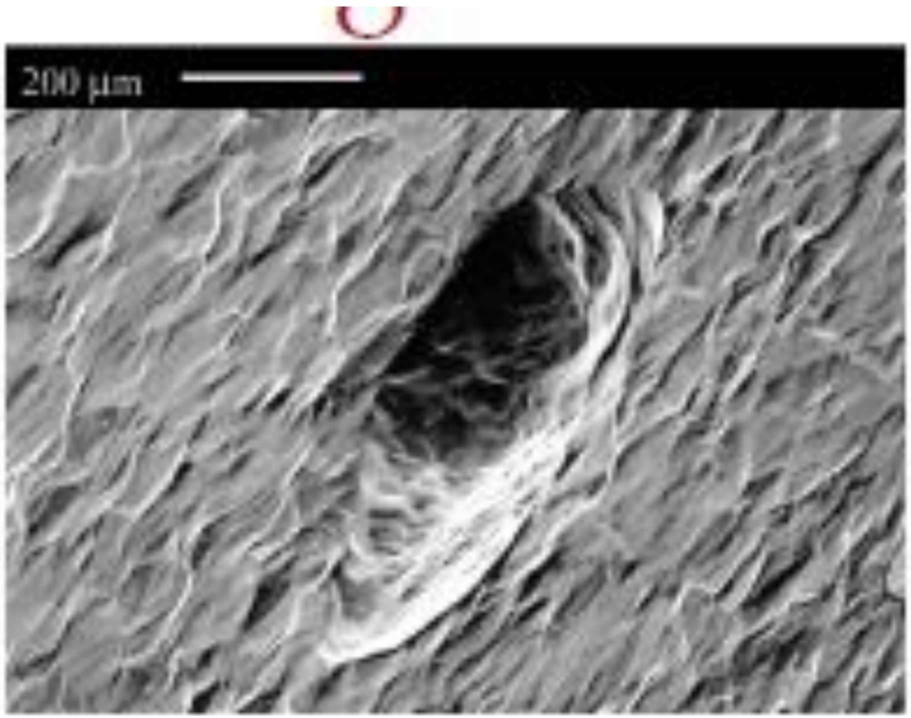
KEK - Cavity Bore-Scope Inspection

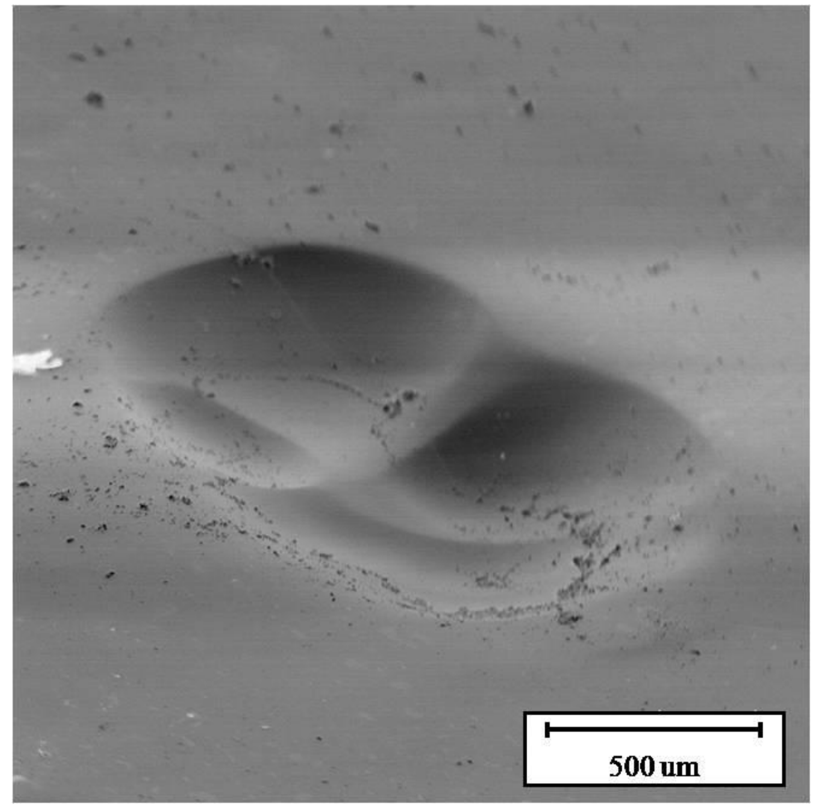


Pits Often found at or near equatorial weld region

- **Camera:**

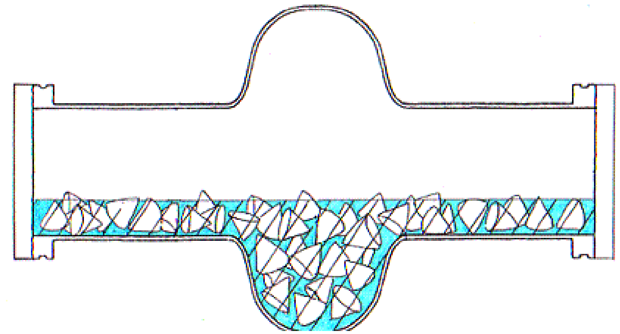
SEM Examination of Pits found after cavity dissection – note local sharp edges



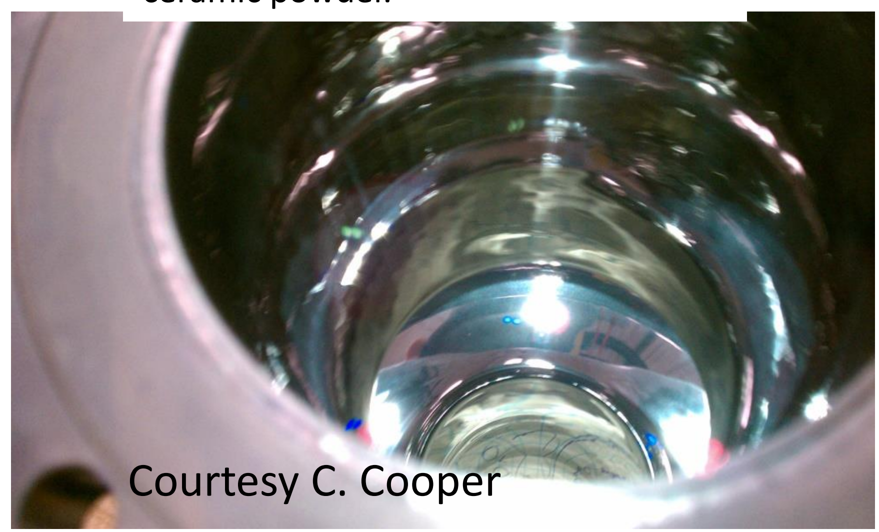


Repair Pit-like Defects
Global Repair by Tumbling

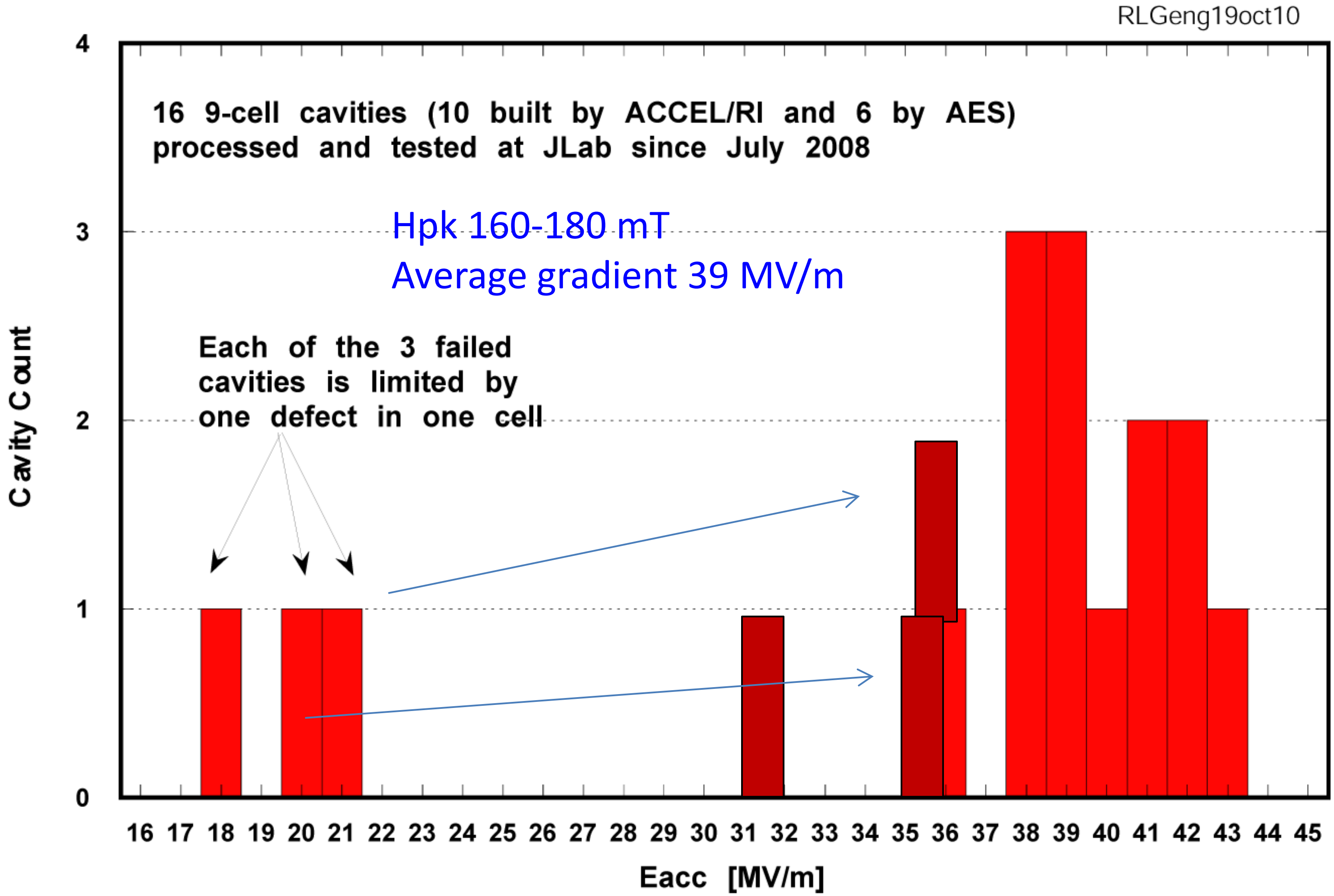
- Produce smooth surface
  - Global mechanical polish



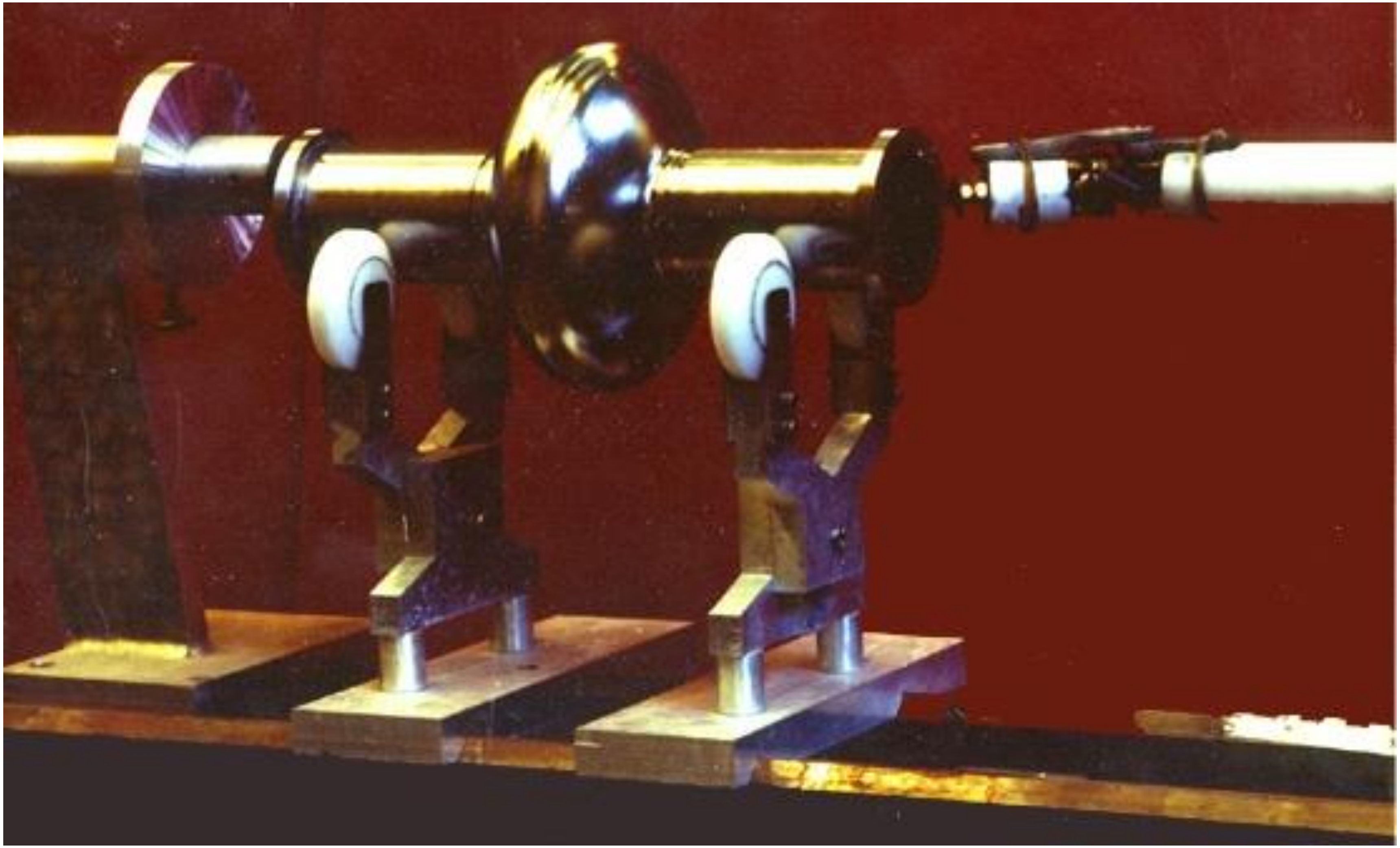
Cavity filled with liquid soap and plastic chips embedded with abrasive ceramic powder.



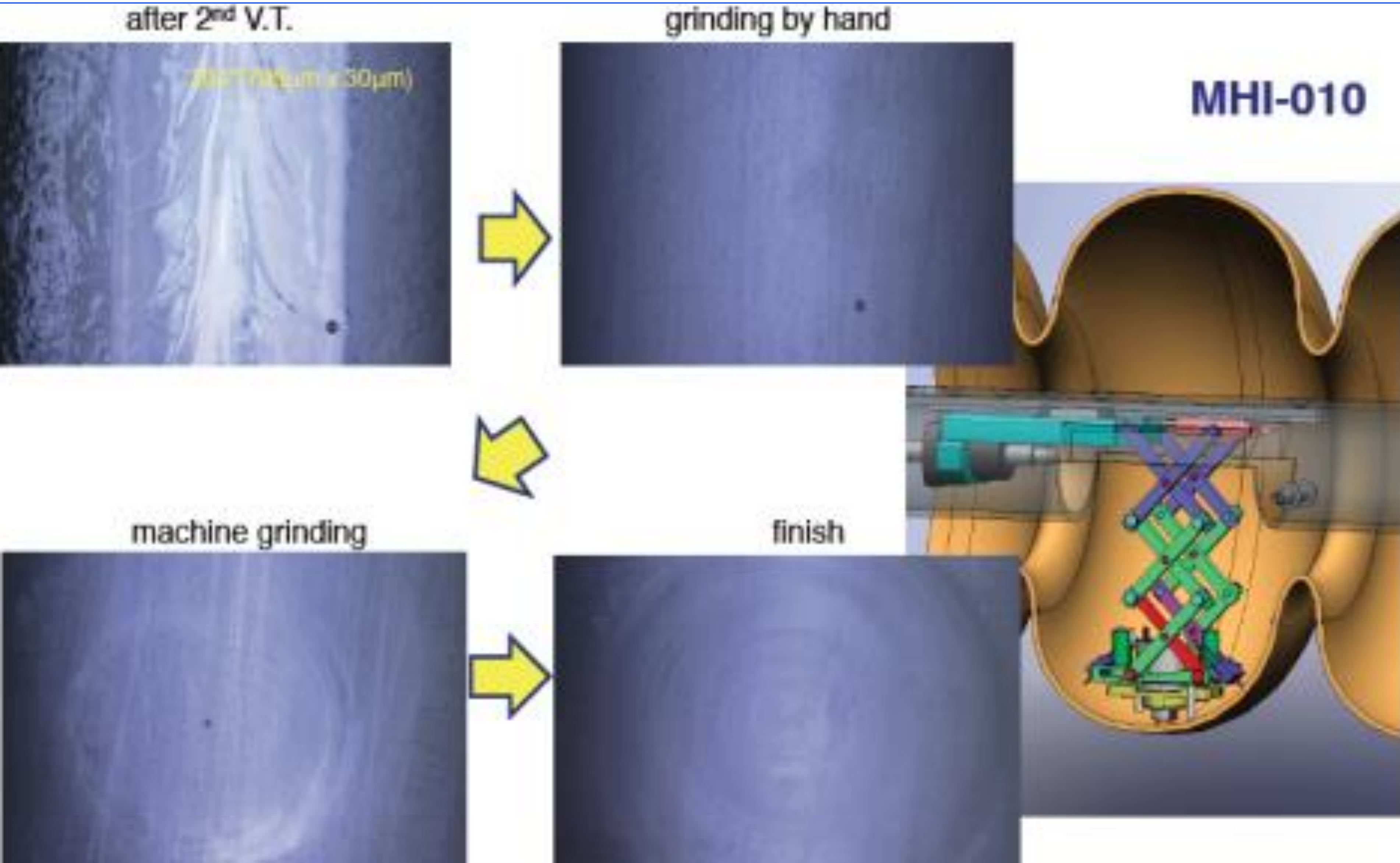
Repaired by Tumbling !



1990 - Repair By Local Grinding at Cornell



2010 Local Repair - KEK



Gradient Limit Understanding and Control

Guided repair at KEK

Cavity	Repaired at (EP/ MT/ LG)	Tested at	Bef.	Aft.	Year
MHI-08	KEK (LG)	KEK	16	27	2009
MHI-14	KEK (LG)	KEK	13	37	2011
MHI-15-1	KEK (LG)	KEK	23	33	2011
MHI-15-2	KEK (LG)	KEK	29	36	2011
MHI-15-3	KEK (LG)	KEK	18	36	2012
MHI-16	KEK (LG)	KEK	21	34	2012
MHI-19	KEK (LG)	KEK	26	37	2012
HIT-2	KEK (LG)	KEK	35	41	2012

Blue: Repaired after the 1st cycle process
Red: Satisfy ILC requirements

Higher Gradient Studies for Future

- Can we get 40 MV/m reliably?
- Can we even get 50 MV/m?
- What is the limit for Nb?
- Brick wall limit, critical magnetic field, 200 mT
- Soft limit, Field emission
- So improve shape to lower Hpk (as much as possible)
- Even if we have to raise Epk…(say 20%)

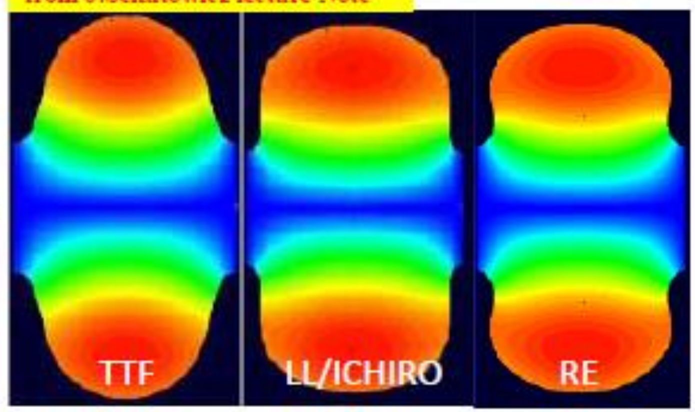
Change Shape to Lower the Surface Magnetic Field

Alternative shape cavities

New Cavity Shape with low Hp/Eacc

$$E_{acc} = \frac{H_{CR}^{RF}}{H_{pk} / E_{acc}}$$

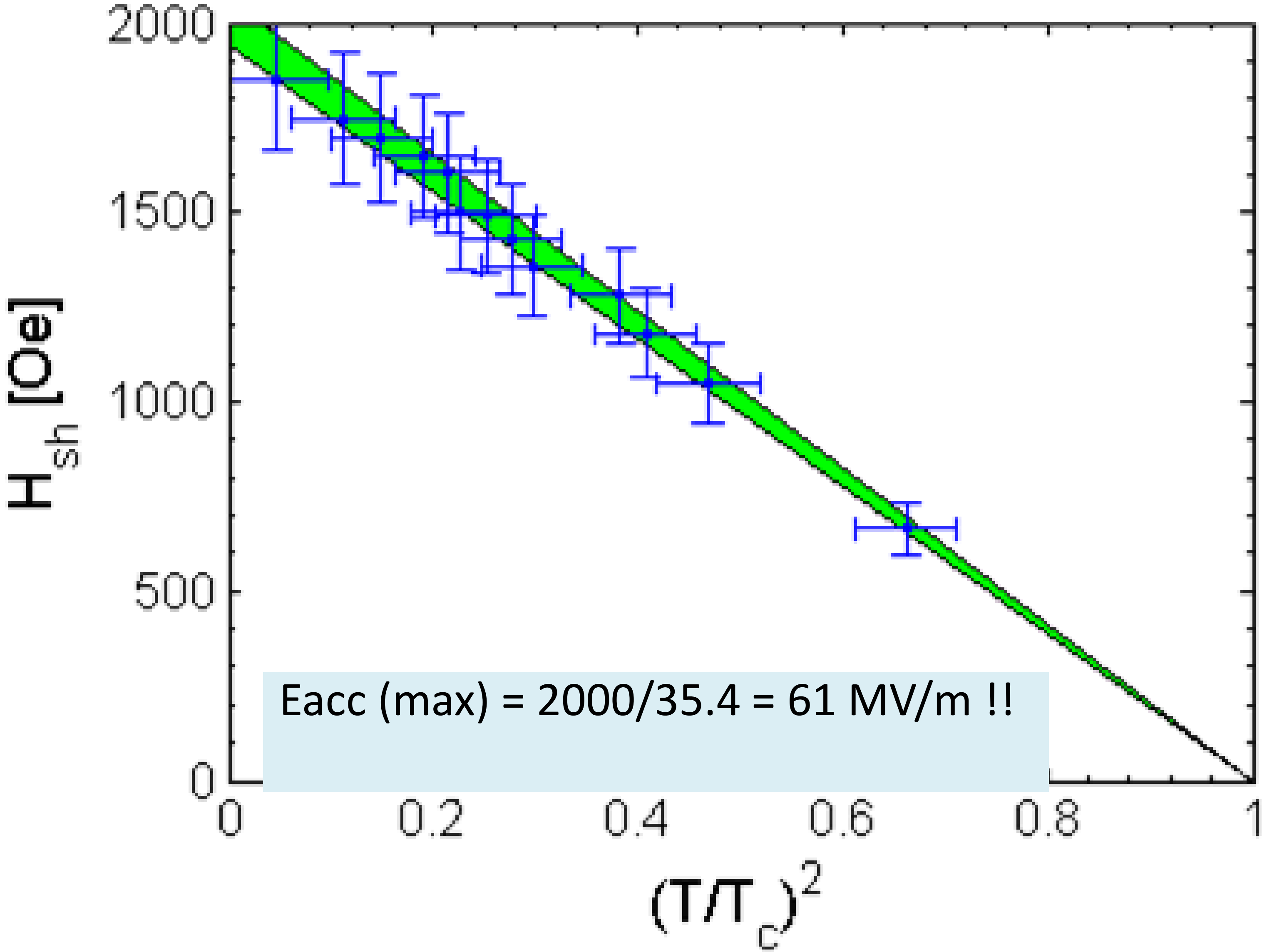
from J.Sekutowicz lecture Note



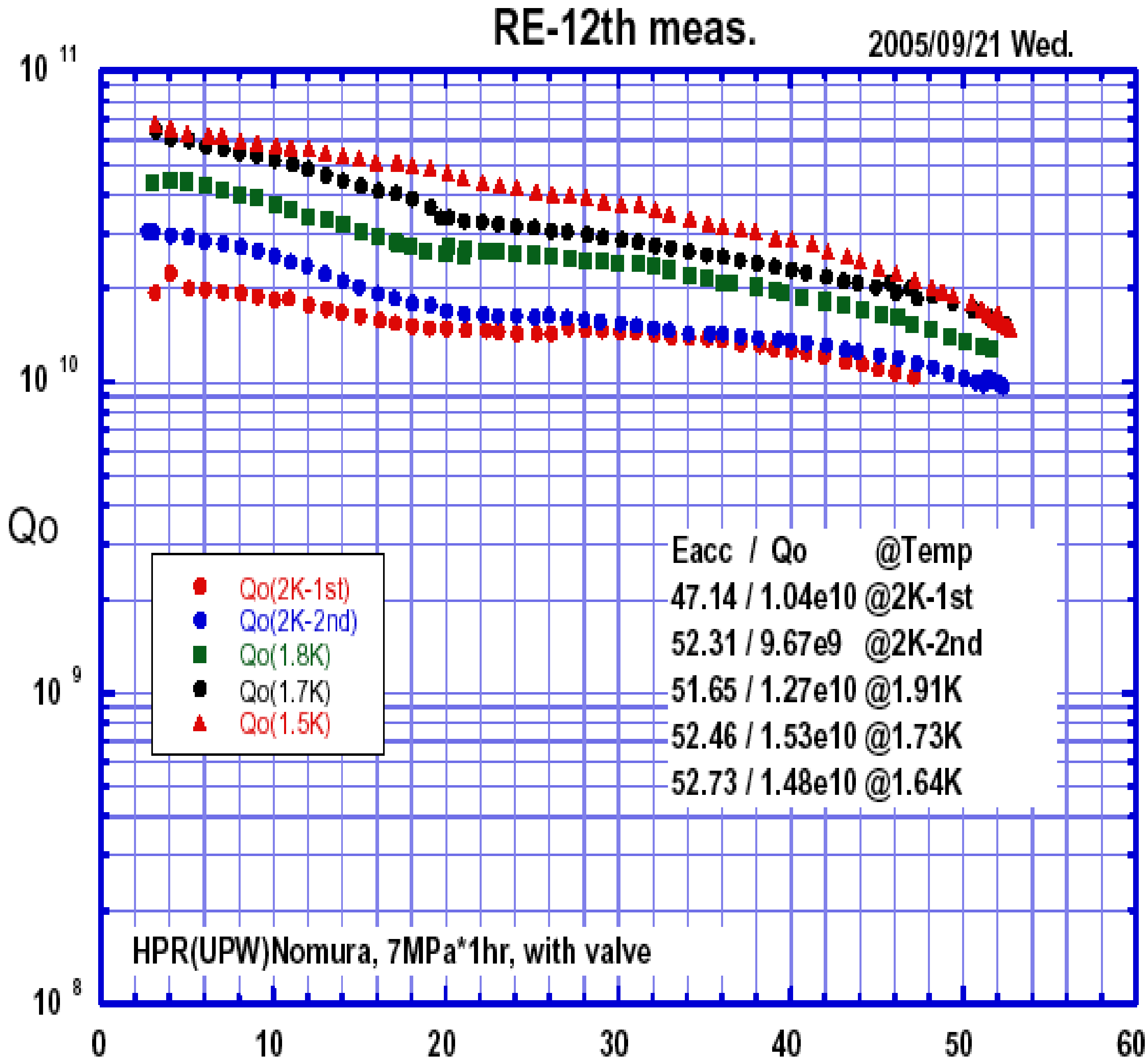
TTF: TESLA shape
Reentrant (RE): Cornell Univ.
Low Loss(LL): Jlab/DESY
LL/ICHIRO: KEK
Low Surface field(LSF): SLAC/Jlab

shape	TTF	LL/ICHIRO	RE	LSF
Iris Diameter [mm]	70	60	60	60
Ep/Eacc	1.98	2.36	2.28	1.98
Hp/Eacc [Oe/MV/m]	41.5	36.1	35.4	37.1
G*R/Q [Ω^2]	30840	37970	41208	36995
Eacc max[MV/m]	42.0	48.5	49.4	47.2

Fundamental RF Critical Field Measurement

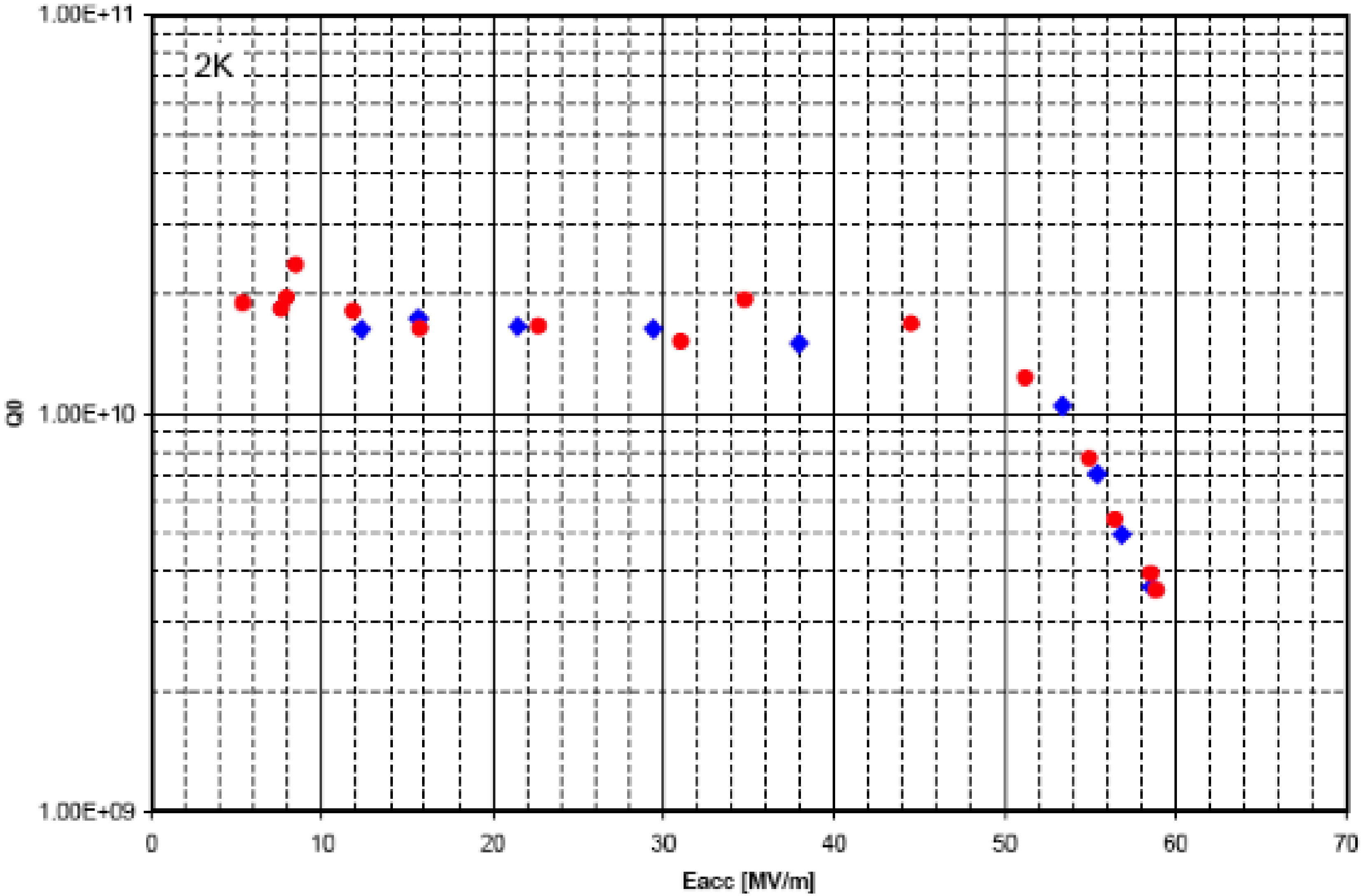


RE single-cell cavity VT



Eacc = 52 MV/m

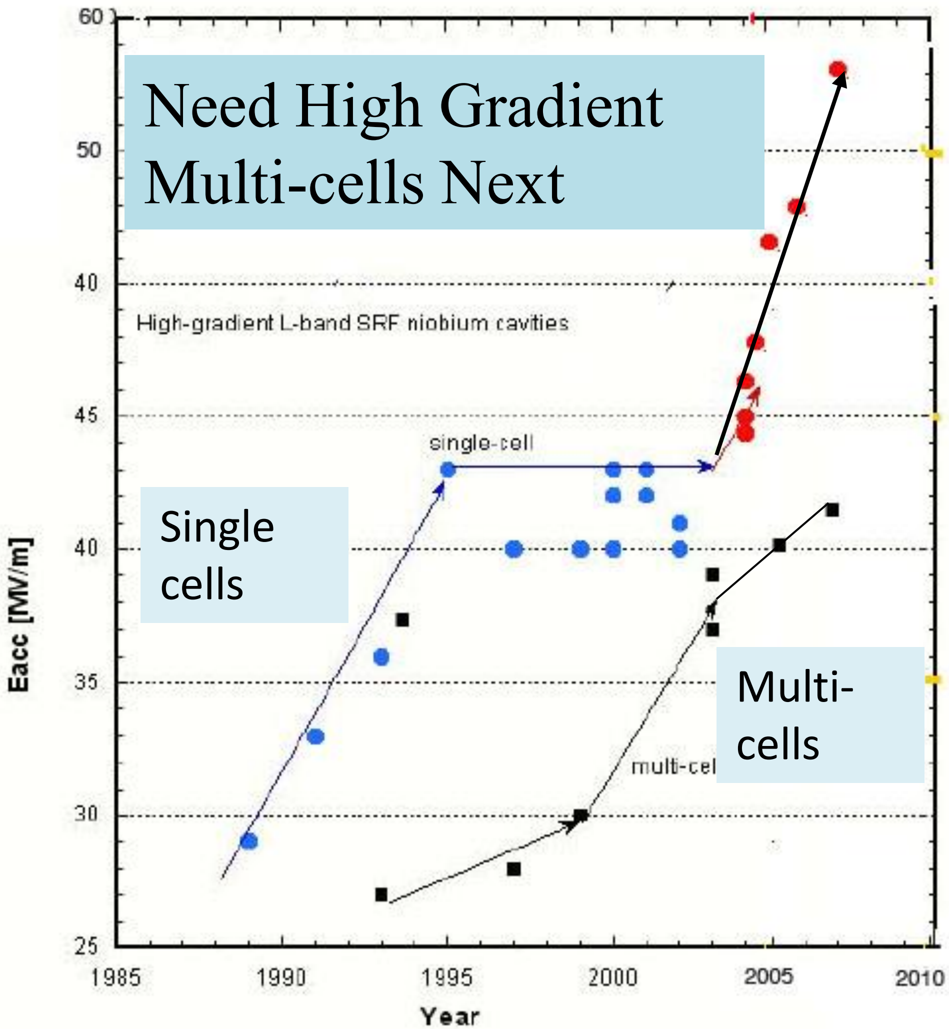
58 MV/M !!

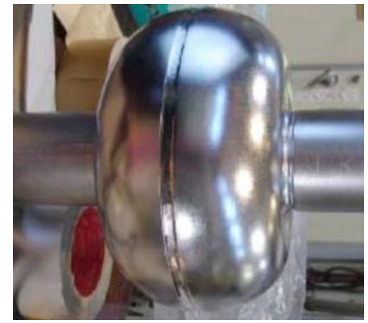


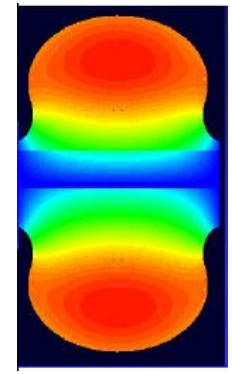
Gradients Beyond 40 MV/m ??

Re-entrant Shapes Reach 57 - 58 MV/m in Single Cells !

Lower Surface Magnetic Field & RF Lower Losses

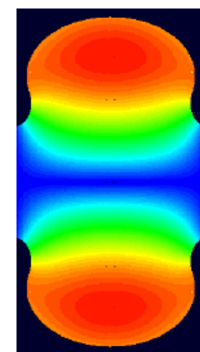






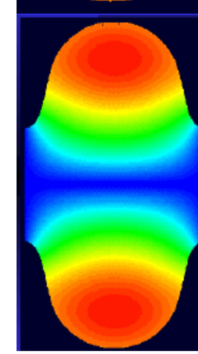
60 mm Re-entrant

Cornell KEK



70 mm Re-entrant

Cornell KEK



70 mm Tesla Shape

Cornell Re-Entrant 9-cell # 1

Present Effort

Prove single cell results in multi-cell cavities – fight field emission Epk/Eacc – 2.4

KEK/Jlab S0-study on ICHIRO#7 in 2010

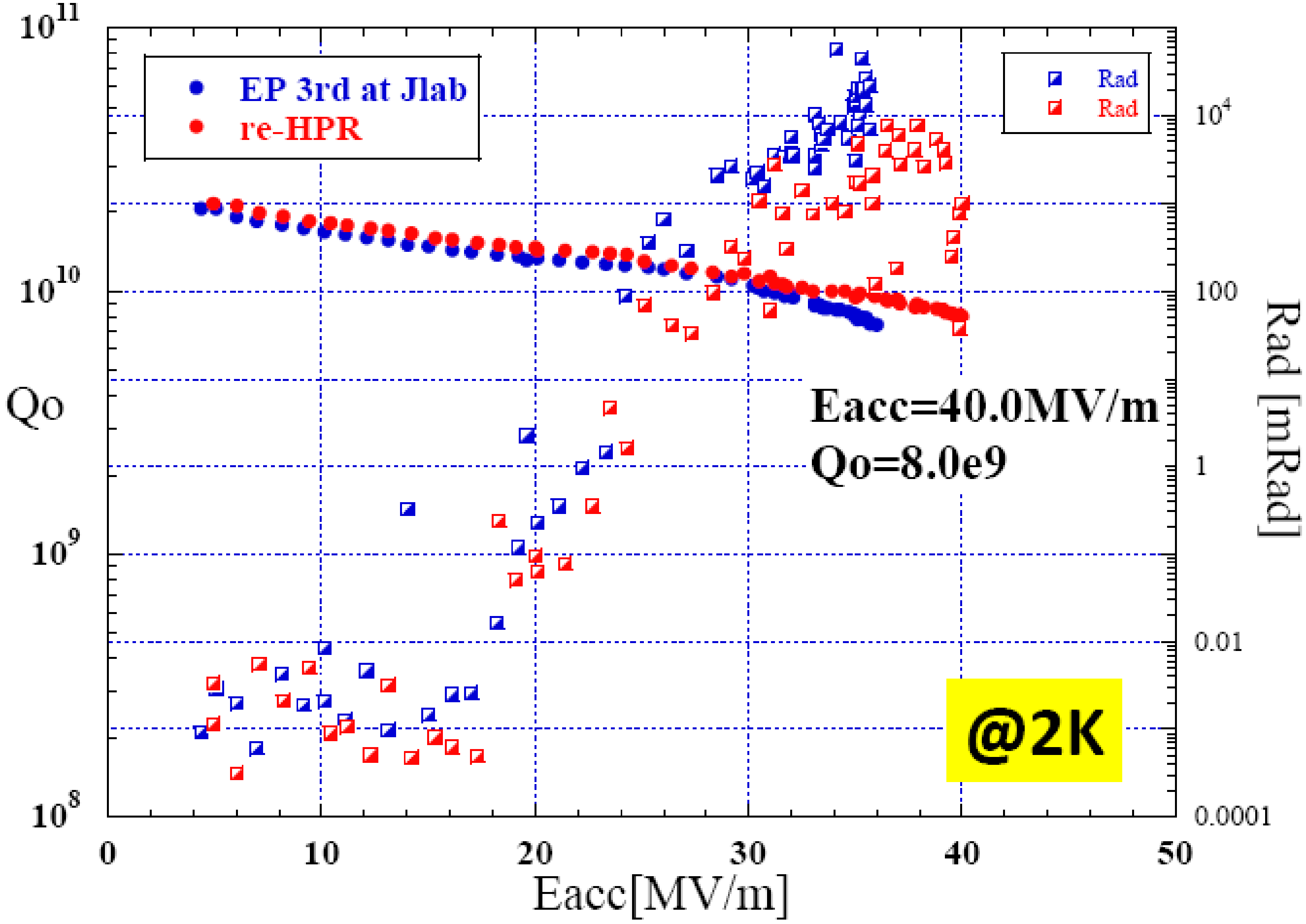
Step-II : full cavity

Ichiro#7

w/ end groups

ICHIRO#7 VT after re-HPR at Jlab

Dec. 14th 2010

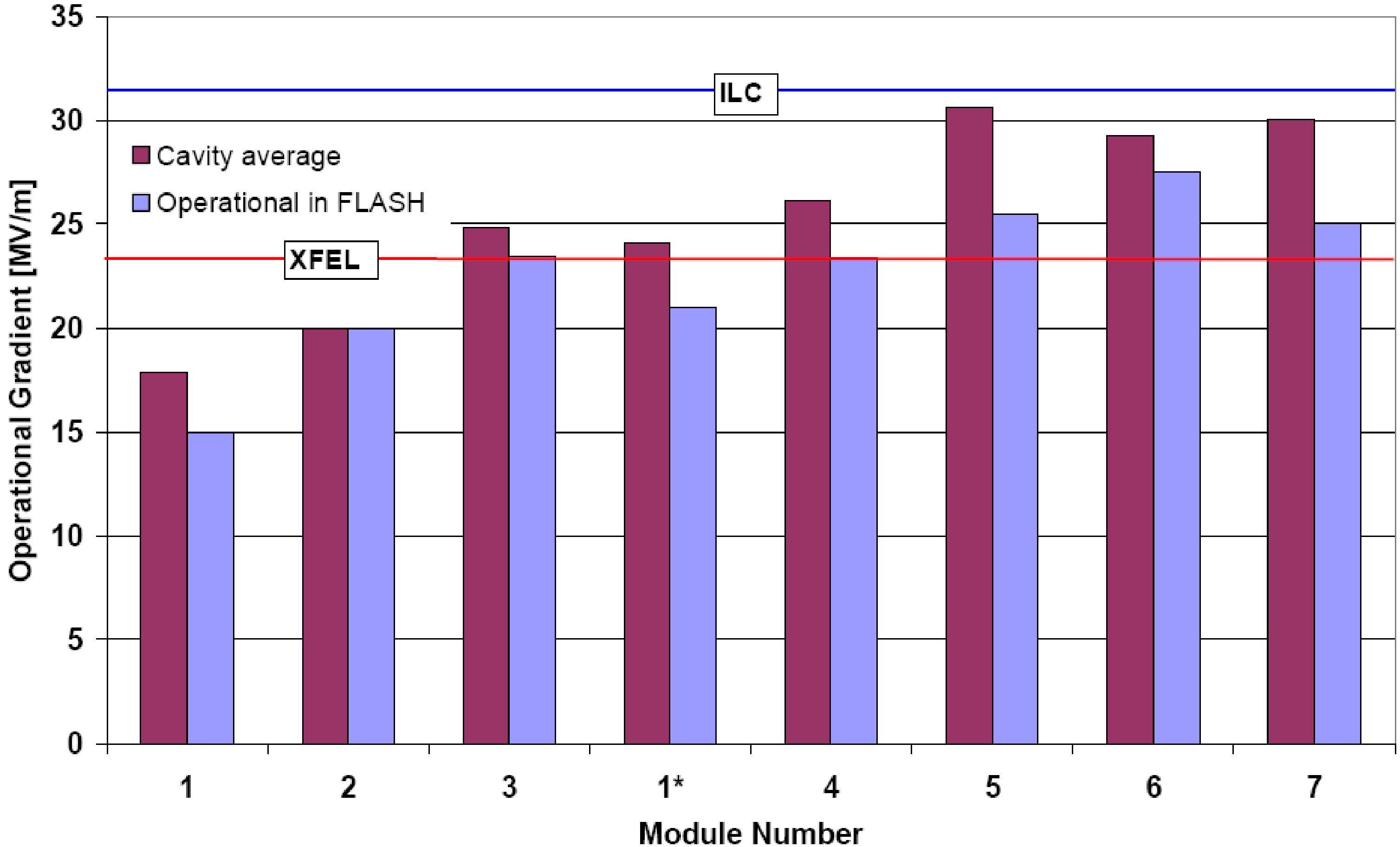


Conclusions

- ILC community reaches desired gradient yield
- World wide industrial involvement
- Path to gradients of 40 MV/m to 50 MV/m established with single cells
- Need to attack field emission more strongly to realize 40 – 50 MV/m in multi-cells.

Back Up Slides

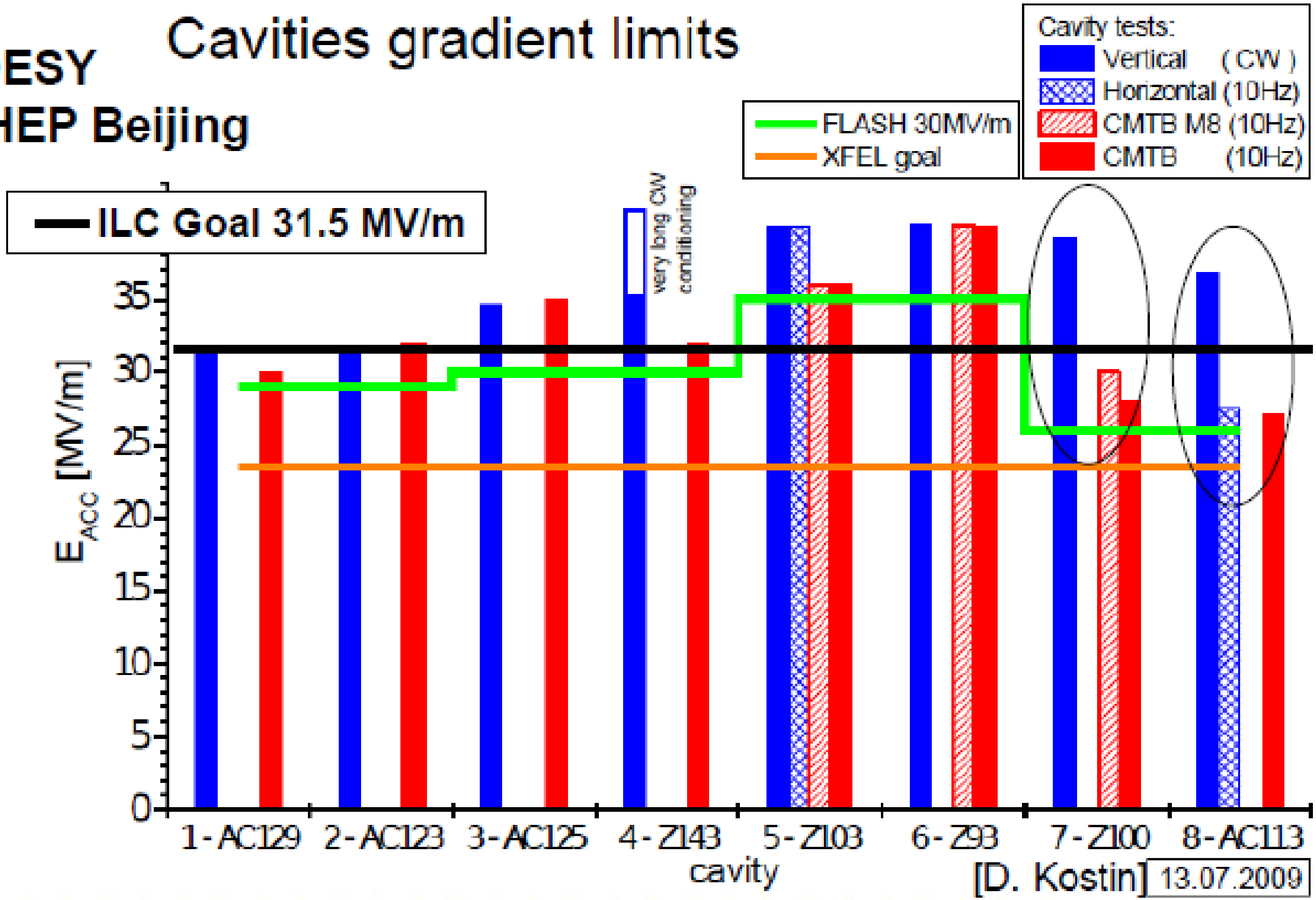
TTF – FLASH CM Gains



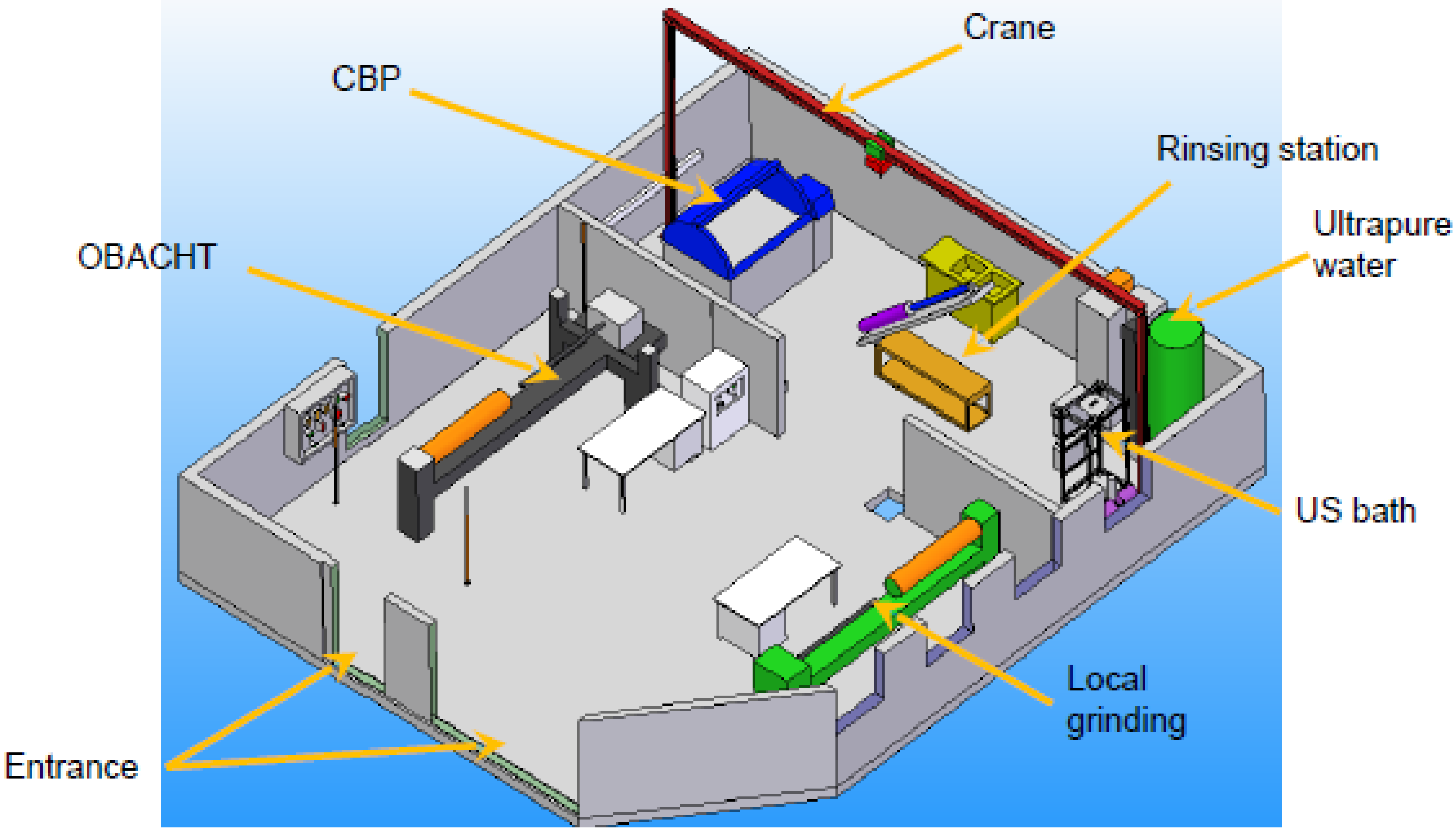
Module performance PXFEL1

DESY
IHEP Beijing

Cavities gradient limits



HiGrade Lab



- 100 m2
- 2 rooms
- to be ready around June 2013

SRF Infrastructure in AMTF

- 2 cryostats
- 6 mounting stations for inserts
- Insert prepared to hold cavities with and without He-tank
- moveable concrete shielding for radiation protection

Insert with shields being moved to cryostat

European ILC-HiGrade programme

XFEL order includes 24 cavities as a part of the ILC-HiGrade program:

- Initially, serve as **quality control (QC)** sample for the ***XFEL***
  - extracted regularly, ~**one cavity/month: first cavity arrived!**
  - after the **normal acceptance test** will be **taken out** of the production flow --> R&D
- Delivered with **full treatment** but **no helium tank**
  -> **maximize** the data output from the test
- Further handling within **ILC-HiGrade/CRISP** **as feasibility study** for **ILC goal**:
  - surface mapping from the 2nd cold RF test
  - optical inspection (OBACHT) and replica
  - Centrifugal Barrel Polishing
  - Local Grinding repair
- Aim for **3 world record modules** from the **24 ILC-HiGrade cavities**